STABILITY CALCULATION FOR THE SURROUNDING ROCK OF POWERHOUSE CAVERN

[UPPER TRISHULI-1 HEP (216MW)]

2022. 05

DOOSAN Enerbility

FOR APPROVAL

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Project

Upper Trishuli-1 HEP (216MW)

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1 General

1.1 Introduction

The underground powerhouse is located within the right bank mountain of Trishuli river with vertical buried depth of about 300m. At present, overall size of powerhouse cavern is L80.0m×W20.6m×H39.4m, size of main transformer cavern, which is located at downside of powerhouse cavern and with net rock wall thickness of about L27.75m, is W15.6m×H12.3m.

According to the previous geological information and contractor's interpretation, inter bedded mica schist and quartz-schist are developed / distributed along cavern axis, as per exposed geological conditions of investigation tunnel end and main access tunnel middle, rock classes are highly assumed as Type II or even partially Type I, Type III may be developed locally.

The proposed supports of powerhouse and transformer caverns are shown in Figure 1-1~1-2. The staged excavation is shown in Figure 1-3.

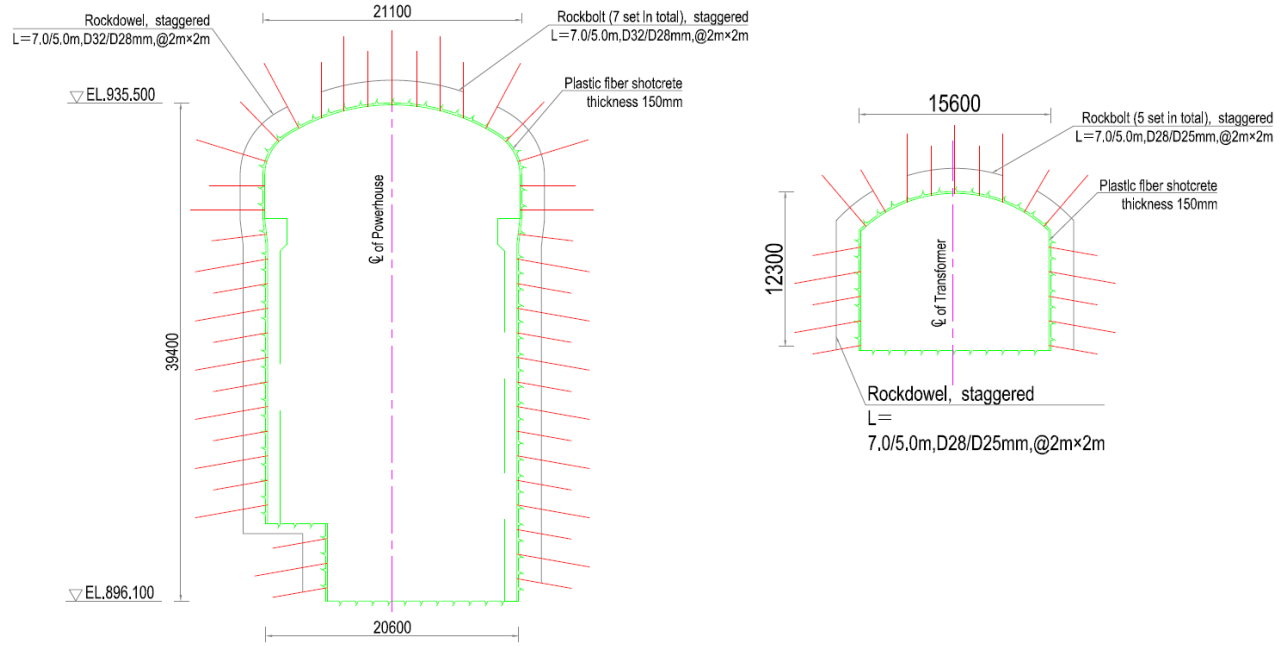


Figure 1-1 Proposed supports of powerhouse and transformer caverns (rock type II)

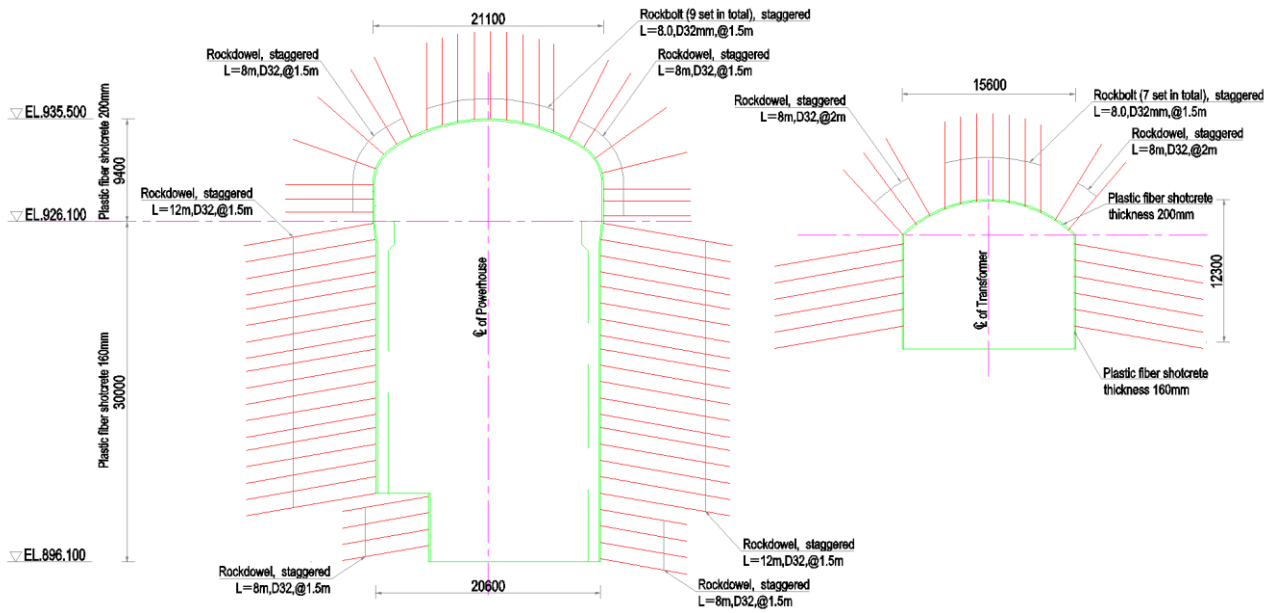


Figure 1-2 Proposed supports of powerhouse and transformer caverns (rock type III)

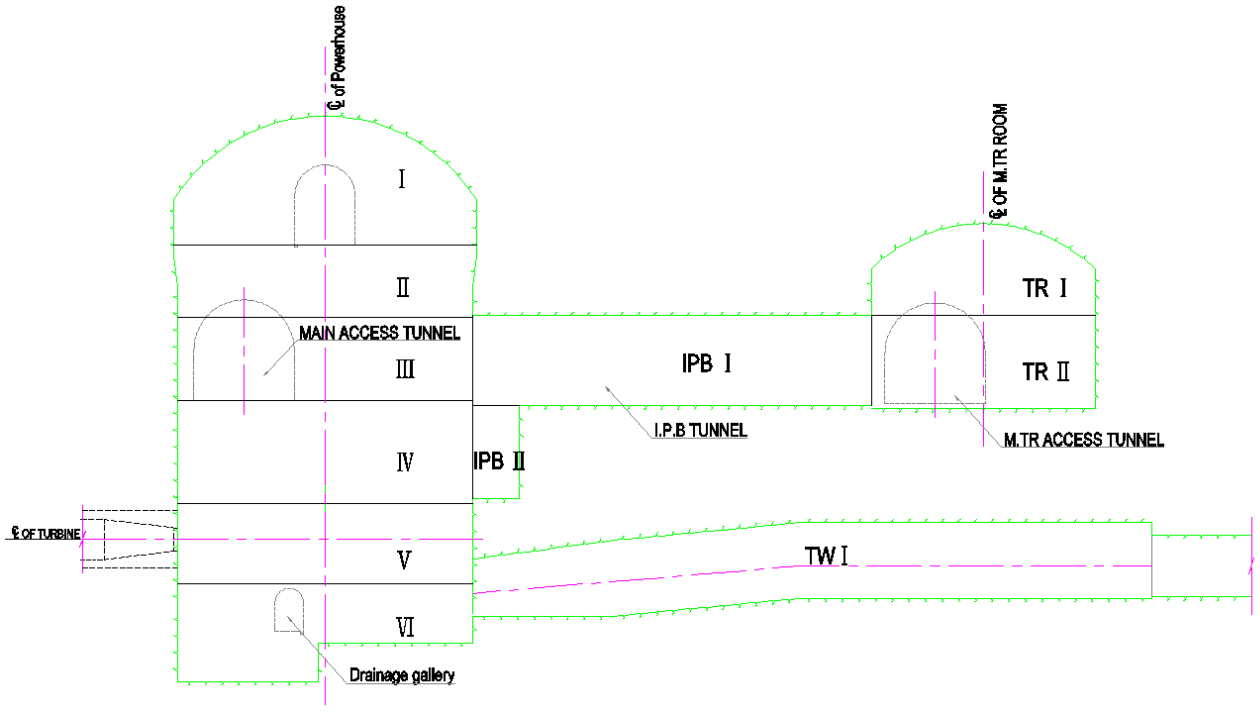


Figure 1-3 Staged excavation plan of powerhouse and transform cavern

1.2 Design Objective

This calculation is aim to verify the proposed supports include rock bolts/dowels and shotcrete be effective and feasible; ensure stability of caverns and safety of construction activities during cavern excavation.

Further 3-D stability analysis is planned to be conducted to provide more reliable information to support design of powerhouse and main transformer caverns.

1.3 References

(1) Contract documents, Employer's Requirement

(2) Tunnels and Shafts in Rock (EM 1110-2-2901)

(3) Regarding general Powerhouse size determination confirmation UT1-HEP-PC-DHI-2022-0271

(4) High Strength Deformed Steel Bars and Wires for Concrete Reinforcement Specification (Fourth Revision) (IS 1786-2008)

(5) Building Code Requirements for Structural Concrete and Commentary (ACI 318)

2 Theoretical Background of Calculations

2.1 Software

Software Phase 2 is applied to conduct the calculation. Phase2 is a powerful 2D finite element program for soil and rock applications. Phase2 can be used for a wide range of engineering projects including excavation design, slope stability, groundwater seepage, probabilistic analysis, consolidation, and dynamic analysis capabilities.

Software UNWEDGE is an interactive software for the stability analysis of three-dimensional wedge formed by structural discontinuity and underground excavation, which is used to analyze the underground excavation problem with discontinuous structural plane in rock mass. UNWEDGE calculates the safety factor of potentially unstable wedge, and can analyze the influence of support system on wedge stability.

2.2 Modeling Conditions, Material Law, Constitutive Model

The modeling conditions are plane strain. The material law is elasto-plastic combined with strain-softening (for rock). The rock mass is modeled as a continuum, homogeneous and isotropic. The failure criteria are the Mohr-Coulomb failure criteria. What needs to be emphasized is that such continuum model with homogeneous and isotropic material is a model, only, and does not necessarily reflect reality. In reality, the displacements occur in blocky rock masses always along discontinuities (joints, foliation etc.), which leads to loosening of the rock mass. The determined plastic zone in the continuums model represents an area of the

rock mass where rock blocks were displaced to each other (= loosening of rock mass). In reality, it does not represent an area where the material was subject to plastic flow, as in soil.

2.3 In situ horizontal stress

For unavailability of field measurement of in situ stresses at the area, gravitational stresses are adopted.

The vertical stress due to the overlying rock is:

$$\sigma_z = \gamma h$$

Where γ represents the density that is the unit weight of the rock.

The horizontal in situ stresses also depend on the depth below surface. They are generally defined in terms of the vertical stress as follows:

$$K_0 = \sigma_h / \sigma_v$$

Where K_0 represents the lateral rock stress ratio. Since there are three principal stresses directions, there will be two horizontal principal stresses. In an undisturbed rock mass, the two horizontal principal stresses may be equal.

In this calculation, K_0 is taken as 1.3 according to topographic and geological conditions of the engineering area.

3 Properties of Materials

3.1 Rock Mass

The mechanical parameters of surrounding rock are shown in Table 3-1 as per approval letter RN 0031.

Table 3-1 Mechanical parameter for surrounding rock of powerhouse caverns

Class of surrounding rock	Q	Unit weight	Poisson's ratio of rock mass	Elastic modulus of rock mass	Rock mass/rock mass shear (shearing) strength				Uniaxial compressive strength of rock mass	Uniaxial compressive strength of intact rock	Tensile strength of rock mass
					Peak		Residual				
		γ (kN/m^3)	μ	Em （GPa）	*C* *（MPa）*	*Φ* *（°）*	*Φr* *（°）*	*Cr* *（MPa）*	UCS rm （MPa）	INTACT UCS r（MPa）	σ_{tm} (MPa)
Ⅱ	10~40	27.0	0.25	20.5	2.5	48	38	0.95	13.0	60	1.3
Ⅲ	4~10	26.5	0.25	10.0	1.0	45	35	0.35	4.8	60	0.48

3.2 Rock Dowel/Rock Bolt

1) Dowel type: cement mortar full length bonded dowel

2) Yield strength: 500MPa

3) Tensile strength: 545MPa (Table 3 of "IS 1786-2008")

4) Elastic modulus: 210000MPa

5) Allowable tensile strength of rock bolt steel: 500MPa/1.5=333MPa. The value 1.5 is safety factor.

3.3 Shotcrete

The mechanical parameters of plastic fiber shotcrete are shown in Table 3-2. Elastic modulus is calculated by formula Ec=4700*fc'^0.5 (ACI 318, section 19.2.2 Modulus of elasticity).

Table 3-2 Mechanical parameter of plastic fiber shotcrete

Compressive strength fc'(MPa)	Tensile Strength (MPa)	Elastic modulus Ec (MPa)	Unit Weight (kN/m^3)	Poisson ratio
25	2.5	23500	24.0	0.2

4 Cavern Support

4.1 Cavern Support per Excavation Class

The proposed supports for each rock type are shown in Table 4-1.

Table 4-1 Proposed supports for each rock type

Item	Unit	proposed supports	
		II	III
Shotcrete thickness	mm	150mm	Roof :200mm Side wall: 160mm
Shotcrete strength	MPa	25	25
Powerhouse cavern supports		Roof and side walls: L=7.0m,φ32mm/L=5.0m,φ 28mm staggered. Amongst, rock bolts are proposed in the central portion of the cavern crown.	Roof: L=8.0m,φ32mm Side walls: L=12.0m,φ32mm Lower side walls: L=8.0m,φ32mm. Amongst, rock bolts are proposed in the central portion of the cavern crown.
Transformer cavern supports		Roof and side walls: L=7.0m,φ28mm/ L=5.0m,φ 25mm. Amongst, rock bolts are proposed in the central portion of the cavern crown.	Roof: L=8.0m,φ32mm Side walls: L=12.0m,φ32mm. Amongst, rock bolts are proposed in the central portion of the cavern crown.
Rock dowels and/or rock bolts spacing within each row	m	2.0	1.5
Rock dowels and/or rock bolts row spacing	m	2.0	1.5

4.2 Safety Factor

The support safety factor for shotcrete is 1.2.

The minimum safety factor for wedges analysis is 2.0.

5 Model Set-up, Boundary and Loading Conditions, Stress Initiation

For the case of gravitational loading, only, boundary and loading conditions to be set as shown below. The lower boundary of the counted domain is fixed in the X and Y directions, two lateral boundaries fixed in the X direction but unconstrained in the Y direction, and the top is free. The load of overburden above the top boundary is automatically applied by the software according to the elevations. Initial stress conditions in the model can be calculated by gravitational loading, or by specifying the relative ground surface elevation.

The finite element model for rock class II and III is shown as Figure 5-1, and the corresponding gravitational loading is shown in the

Table 5-1.

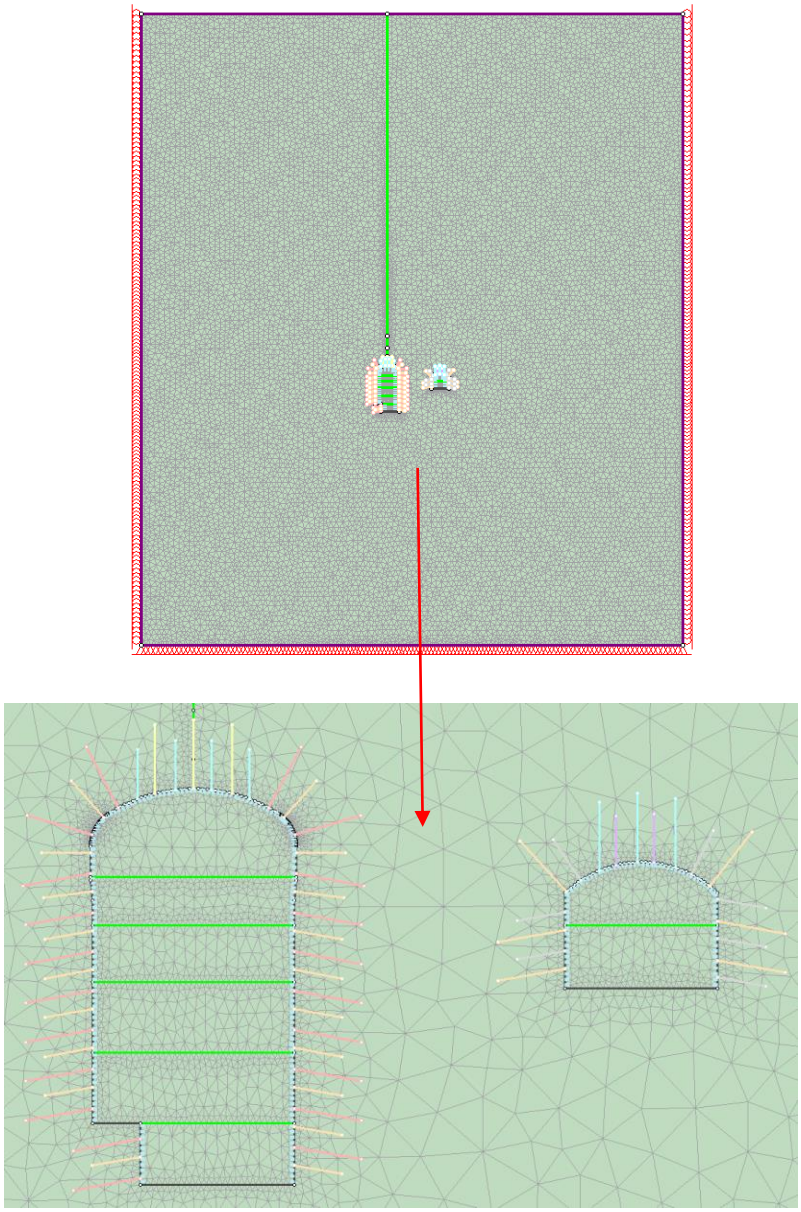


Figure 5-1 Finite element model and boundary conditions

Table 5-1 Gravitational loading for surrounding rock

Rock class	Buried depth	Rock unit weight	Overburden gravitational loading
	m	kN/m³	MPa
II	304.5	27	8.2
III	304.5	26.5	8.1

Prior to application of rock supports, stress release ratio of the surrounding rock takes 50% based on experience, which means that load to be borne by the supporting measures is assumed to be 50% of the ground in-situ stress at the corresponding location.

Initial stress filed of the simulation domain are as shown in Figures 5-2~5-3.

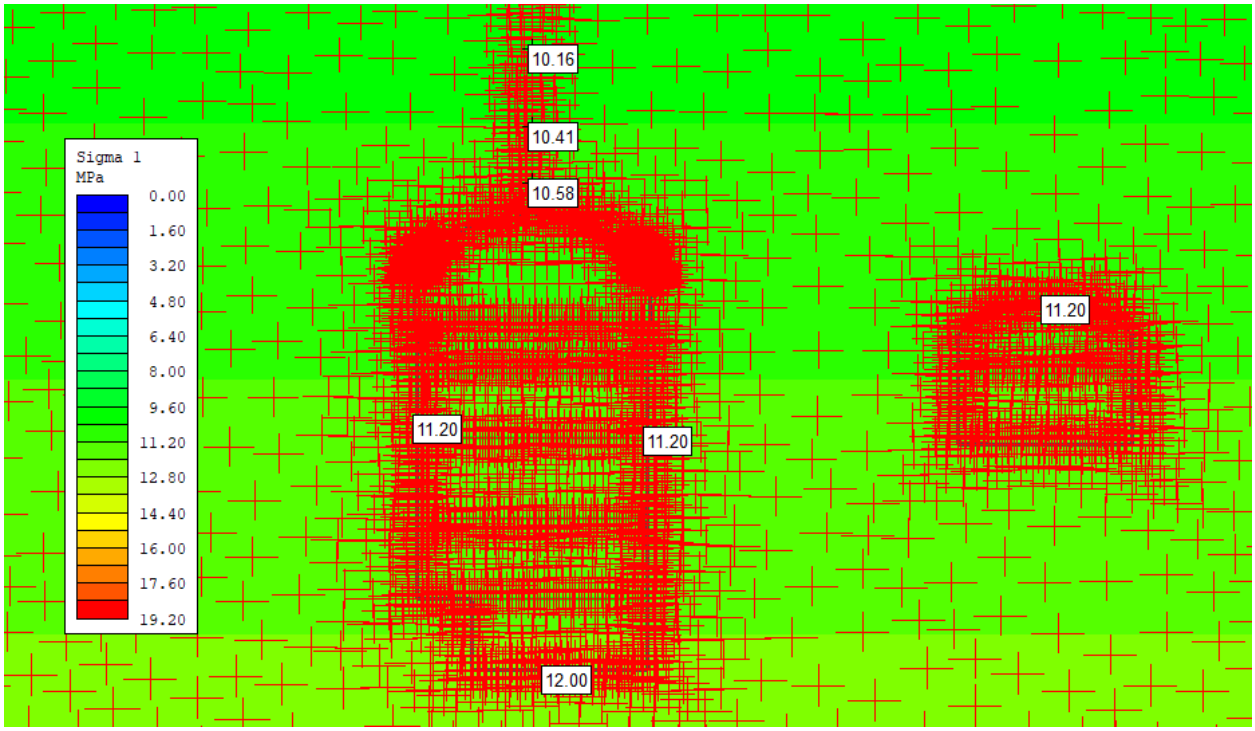


Figure 5-2 Initial stress trajectories (Rock Class II)

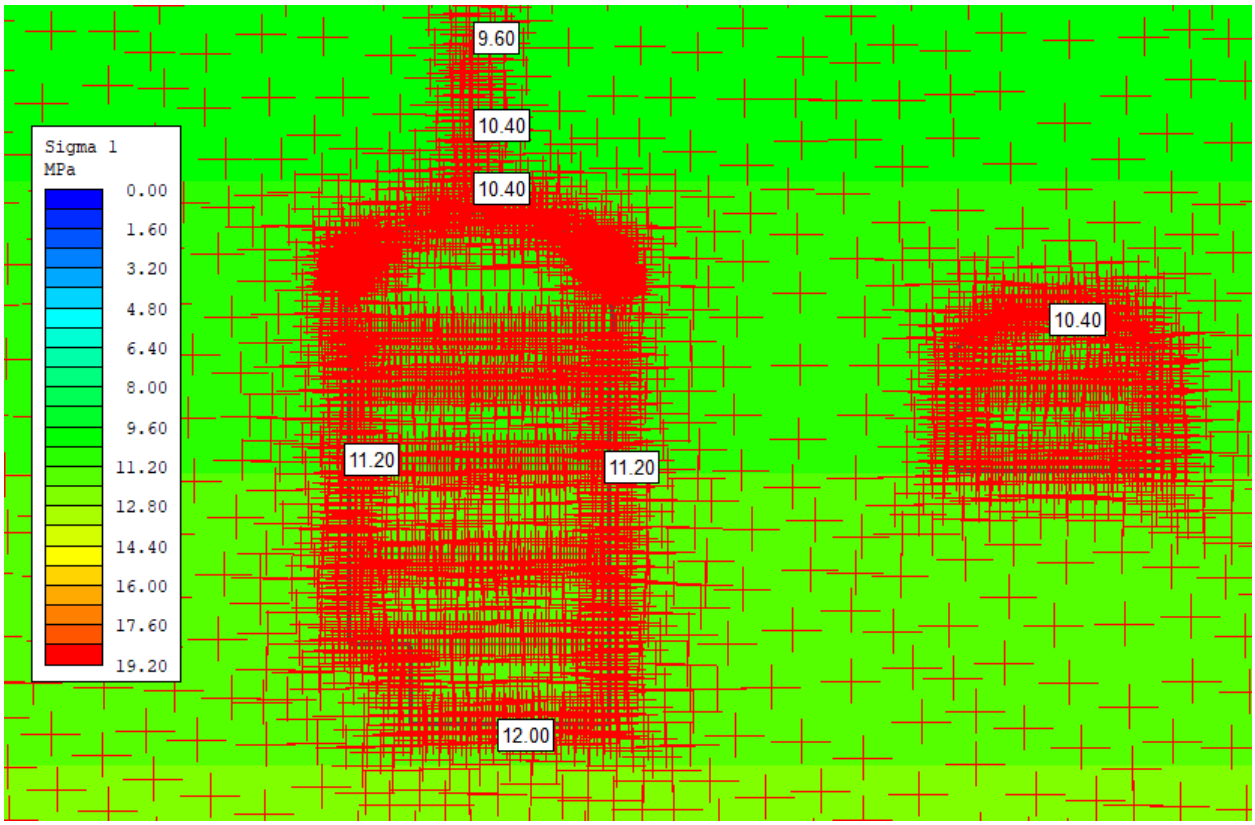


Figure 5-3 Initial stress trajectories (Rock Class III)

6 Calculation Results

6.1 Rock class II (Basic design supporting scheme)

According to bid documents, annexes, section VII, annex 5, 07 powerhouse drawings, supports of the powerhouse and transformer caverns is as below and shown in Figure 6.1-1.

(1)Powerhouse cavern

Roof: rock dowels, φ32mm, spacing 2.0m, L=8.0m.

Side wall: rock dowels, φ32mm, spacing 2.0m, L=12.0m.

(2)Transformer cavern

Roof: rock dowels, φ32mm, spacing 2.0m, L=8.0m.

Side wall: rock dowels, φ32mm, spacing 2.0m, L=12.0m

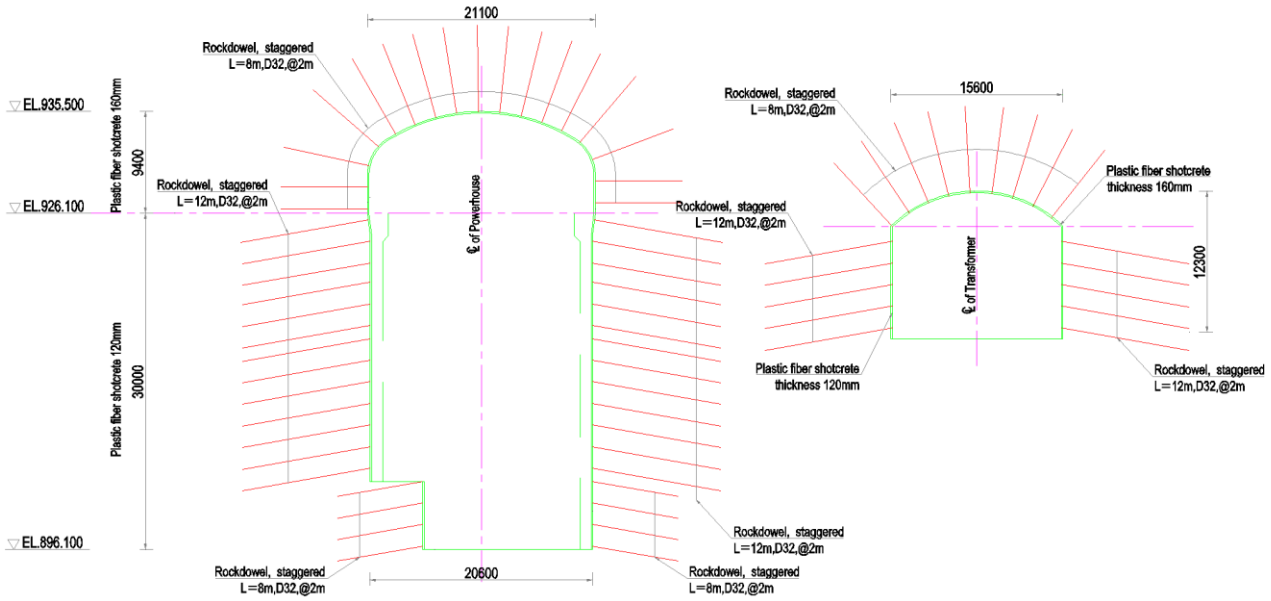


Figure 6.1-1 Basic design supports of powerhouse and transformer caverns (rock type II)

Calculation result is as shown in Figures 6.1-2~4.

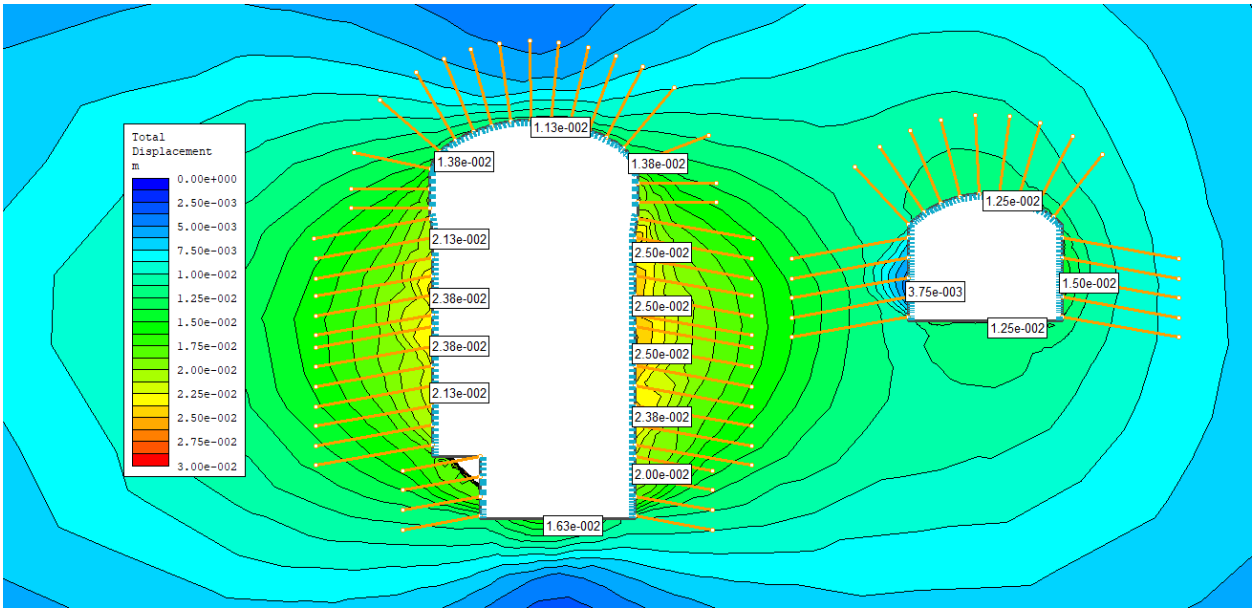


Figure 6.1-2 Total displacement after support installation (Rock Class II)

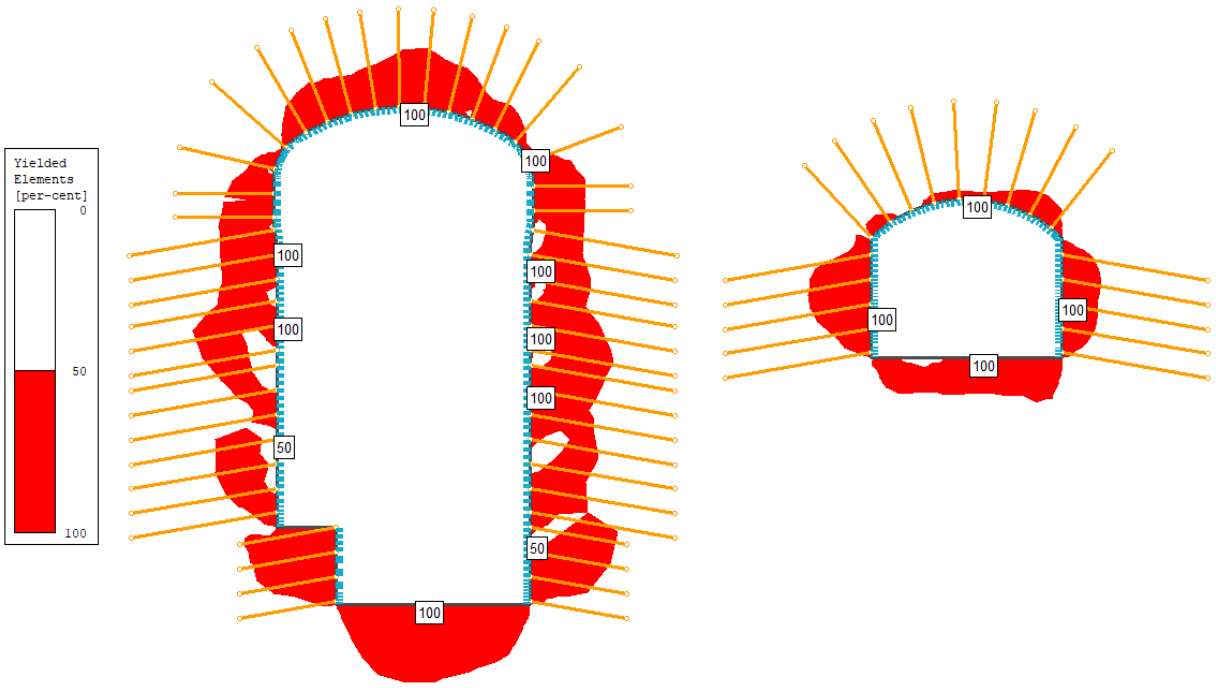


Figure 6.1-3 Plastic zone after support installation (Rock Class II)

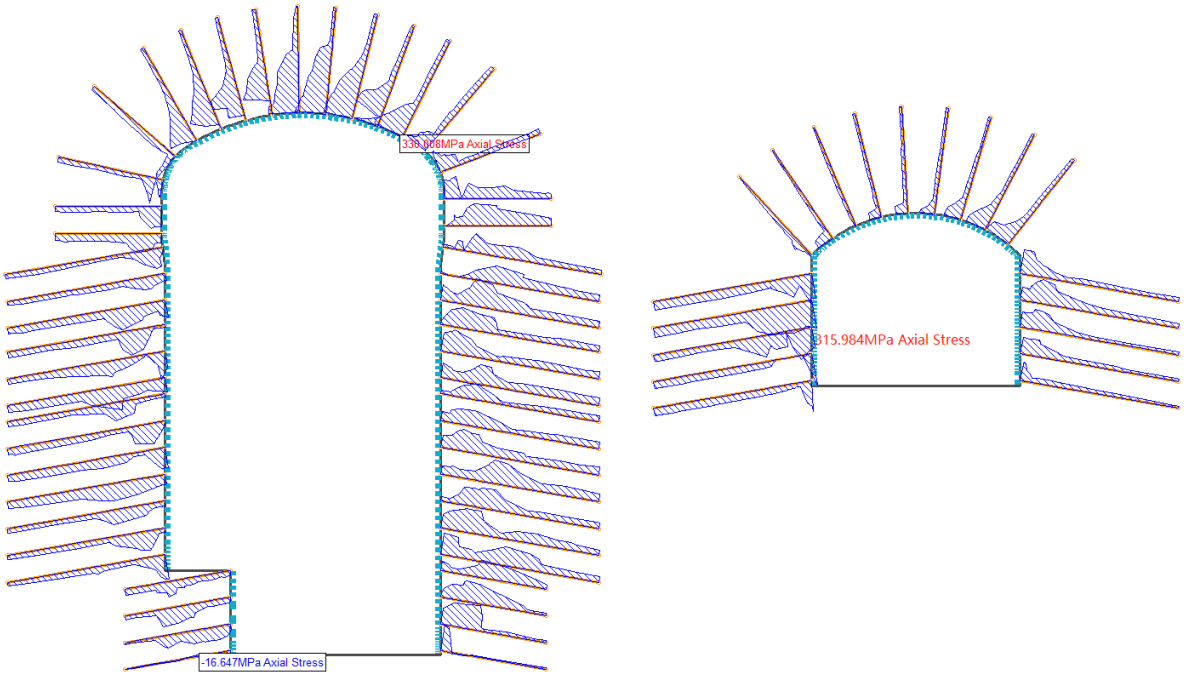


Figure 6.1-4 Axial stress of rock dowels after support installation (Rock Class II)

6.2 Rock class II (prop supports)

From the calculation results shown above, it can be seen that supports of the powerhouse and transformer

caverns in class II surrounding rock were overdesigned in the basic design stage, mainly the rock dowel length, so a new set of supporting parameters is proposed as below and shown in Figure 6.2-1~6.2-3. Furthermore, in order to limit the reflection of the cavern crown effectively, rock bolts are recommended to be applied vertically at the central portion of the cavern crown instead of the rock dowels originally proposed.

(1)Powerhouse cavern

Periphery: rock dowels and bolts, φ 32mm, L=7.0m/ φ 28mm, L=5.0m, spacing 2.0m, staggered. Pre-tensioned bolt instead of central portion of cavern crown (7 bolts).

(2) Transformer cavern

Periphery: rock dowels and bolts, φ 28mm, L=7.0m/ φ 25mm, L=5.0m, spacing 2.0m, staggered. Pre-tensioned bolt instead of central portion of cavern crown (5 bolts)

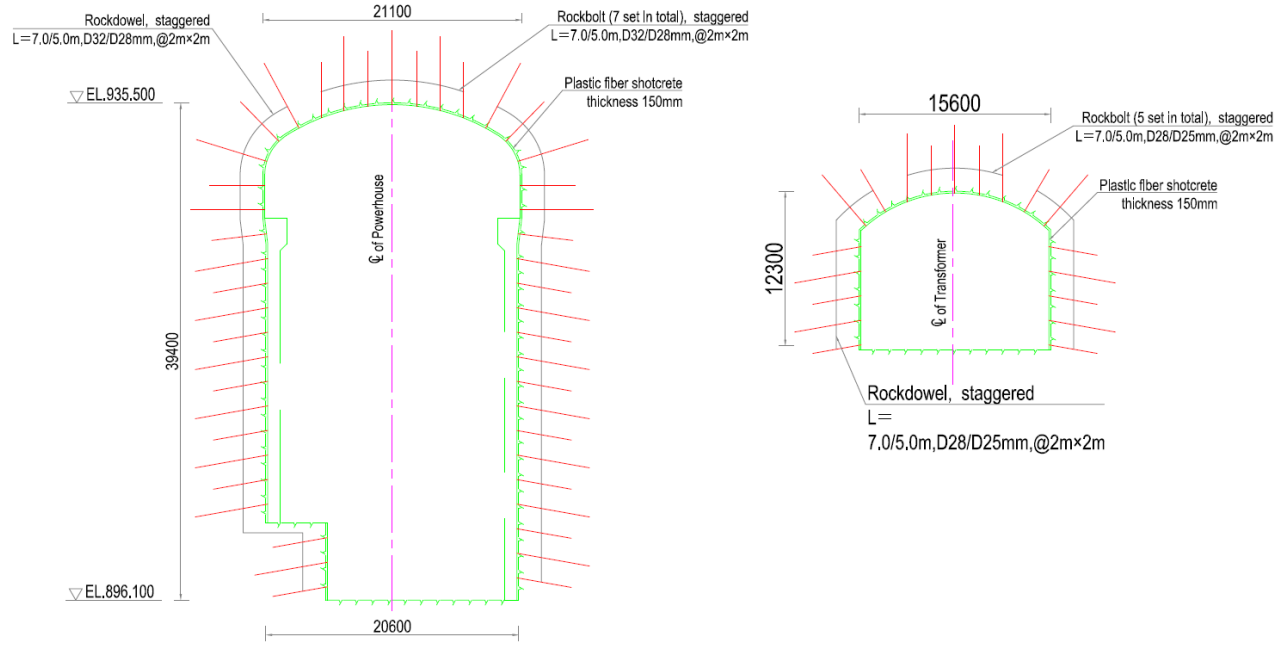


Figure 6.2-1 Prop supports of powerhouse and transformer caverns (rock type II)

Calculation result is as shown in Figures 6.2-2~6.2-4.

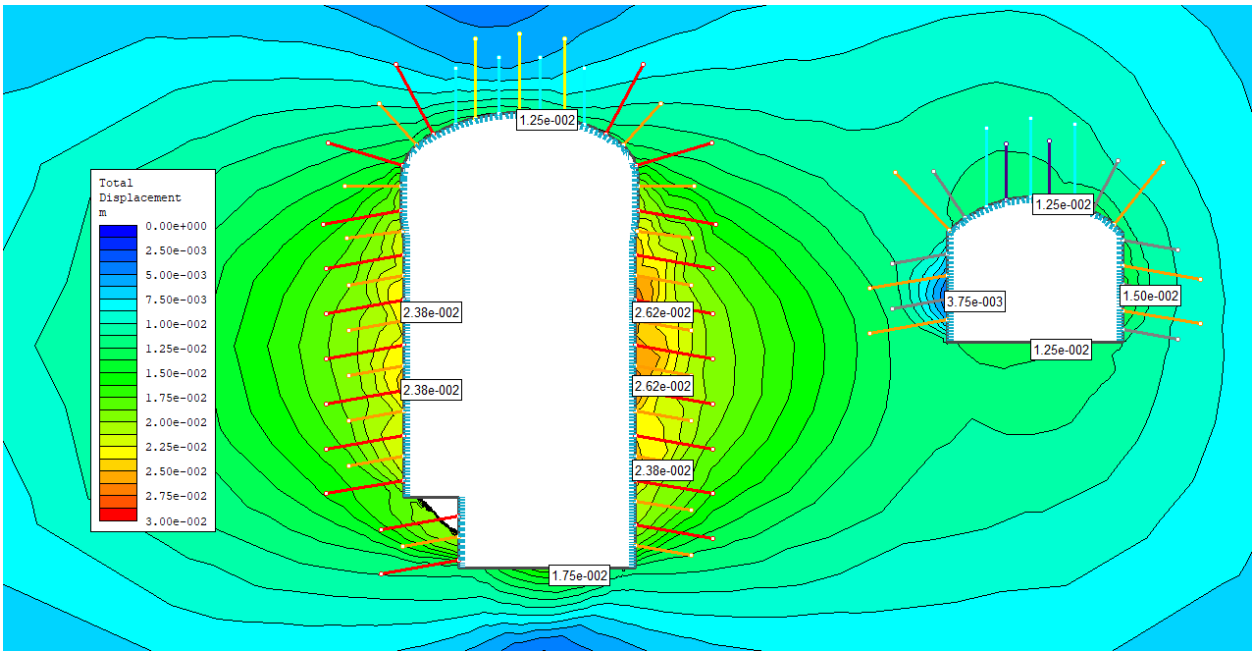


Figure 6.2-2 Total displacement after support installation (Rock Class II)

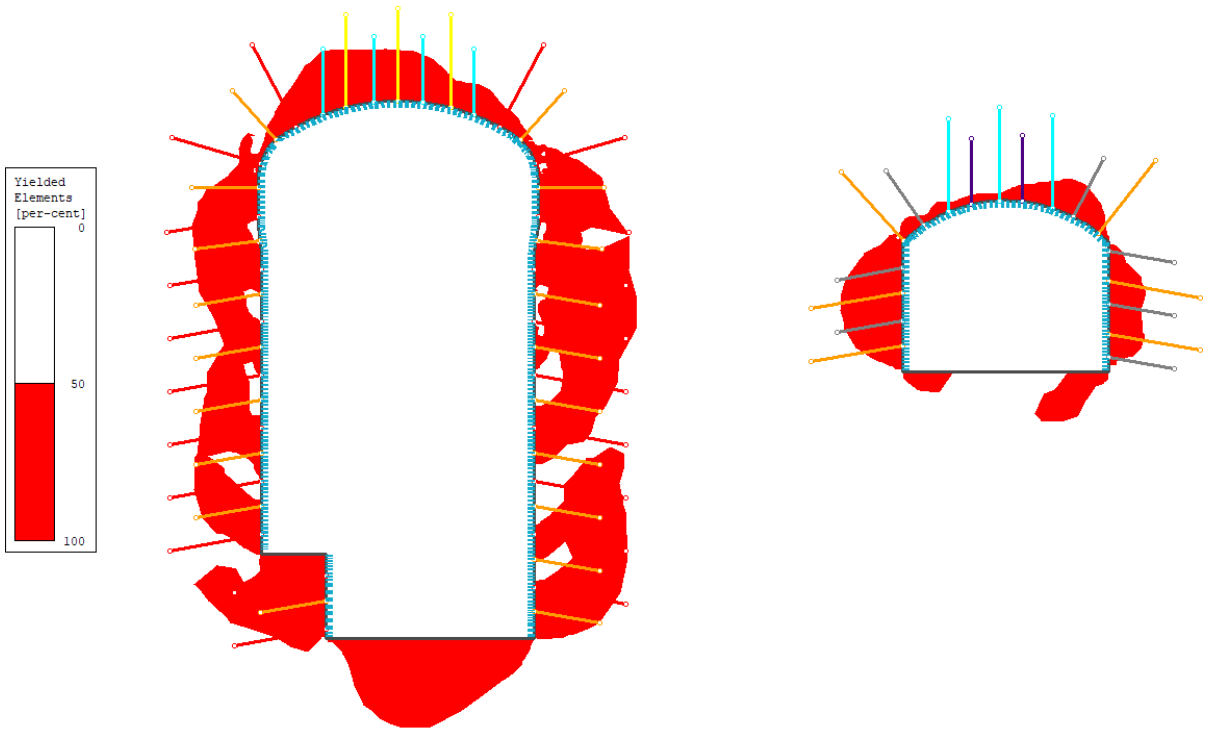


Figure 6.2-3 Plastic zone after support installation (Rock Class II)

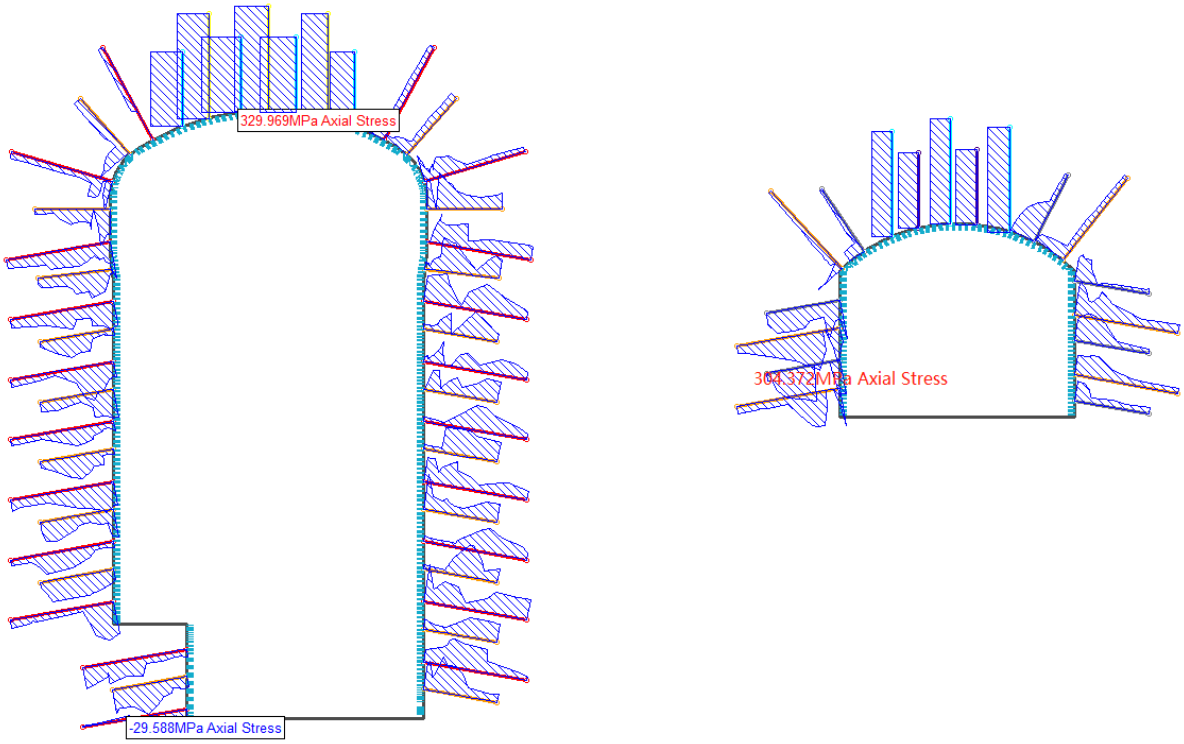


Figure 6.2-4 Axial stress of rock dowels/rock bolts after support installation (Rock Class II)

6.3 Displacement of powerhouse cavern crown surrounding rock (prop supports)

According to calculation result, the vertical displacement of powerhouse cavern crown surrounding rock at different depths (3m, 8m, 15m, 25m away from vault line respectively, which are at the same locations as the monitoring points of extensometer) are shown as follows.

Table 6.3-1 **Vertical displacement of powerhouse cavern crown surrounding rock at different depths**

Unit: m

Stage	Depths of probing points (m)			
	3	8	15	25
I	0	0	0	0
II	0.005885213	0.004423797	0.003258607	0.002397432
III	0.006729652	0.004297505	0.003329766	0.002659152
IV	0.007697082	0.004446901	0.00357695	0.002953608
V	0.007781029	0.004122965	0.003343957	0.002833747
VI	0.008082093	0.003923077	0.003207341	0.002802599

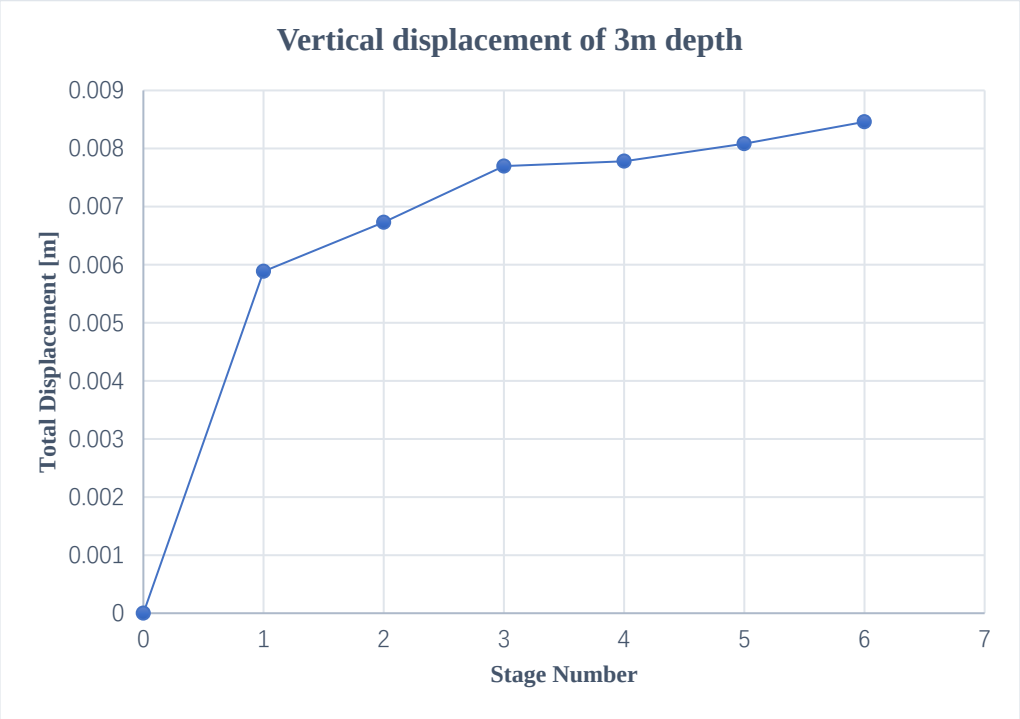


Figure 6.3-1 Vertical displacement development with excavation stages at 3m depth

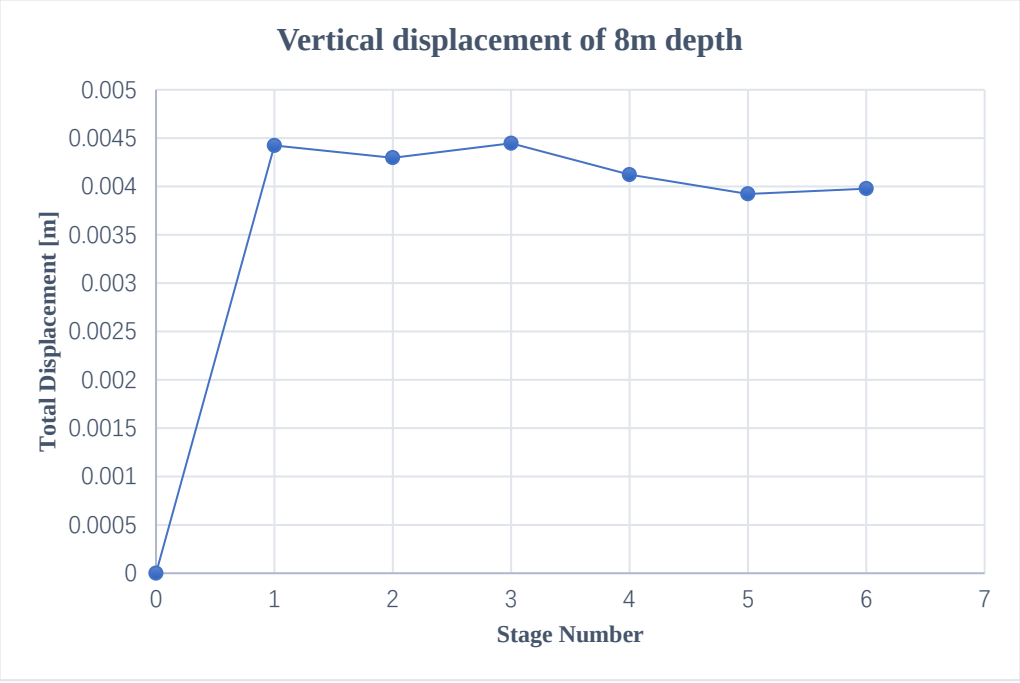


Figure 6.3-2 Vertical displacement development with excavation stages at 8m depth

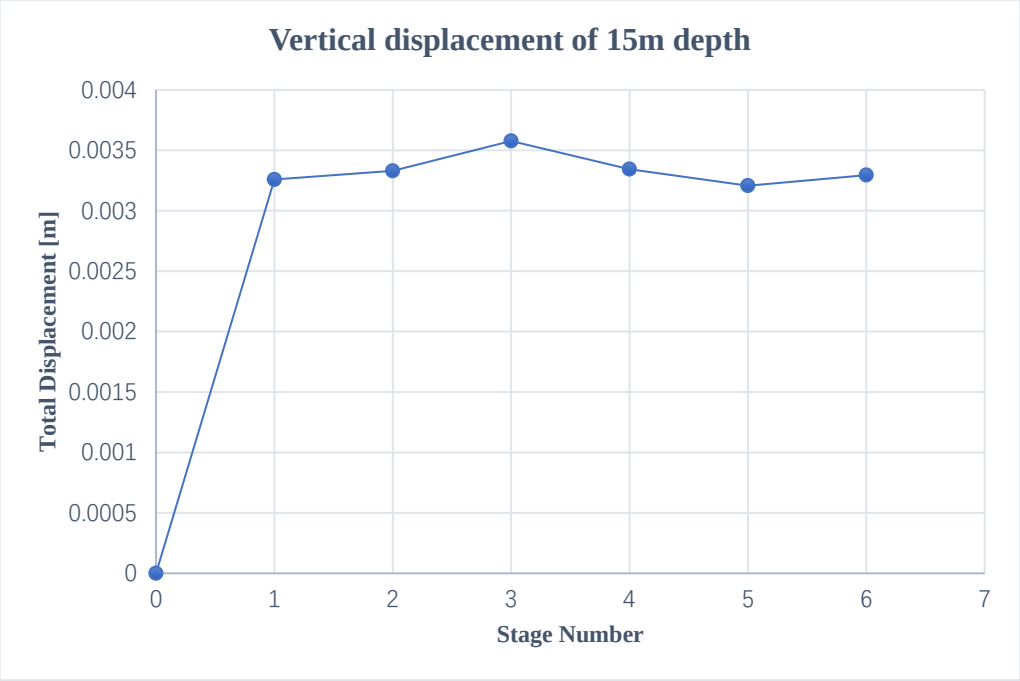


Figure 6.3-3 Vertical displacement development with excavation stages at 15m depth

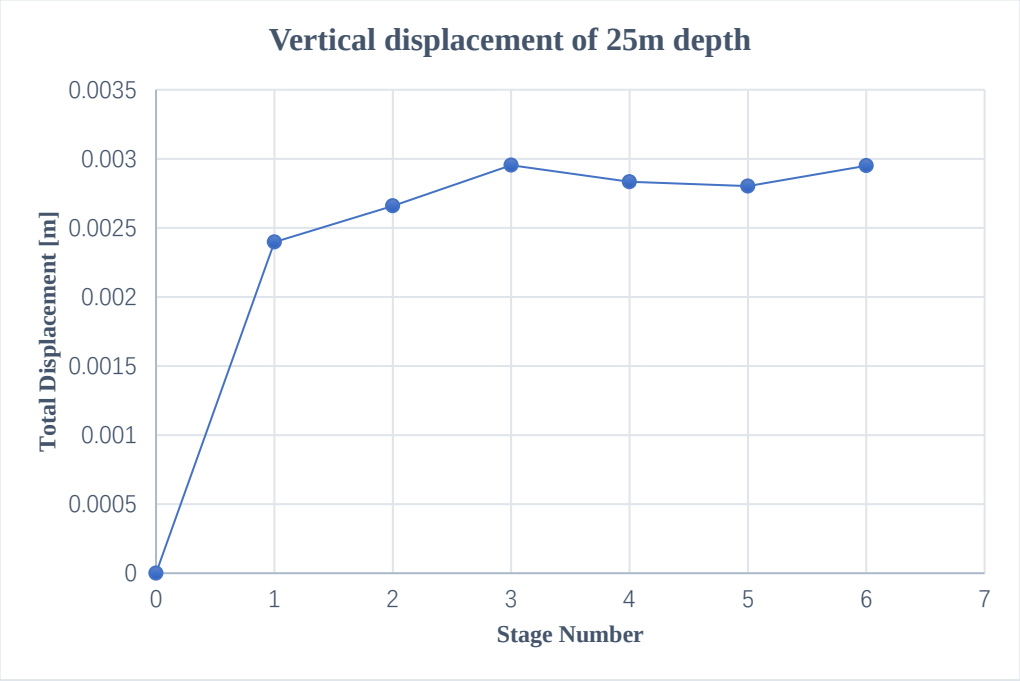


Figure 6.3-4 Vertical displacement development with excavation stages at 25m depth

6.4 Rock dowels/bolts stress (prop supports)

According to calculation result, the stress of typical rock dowels/bolts are shown as follows.

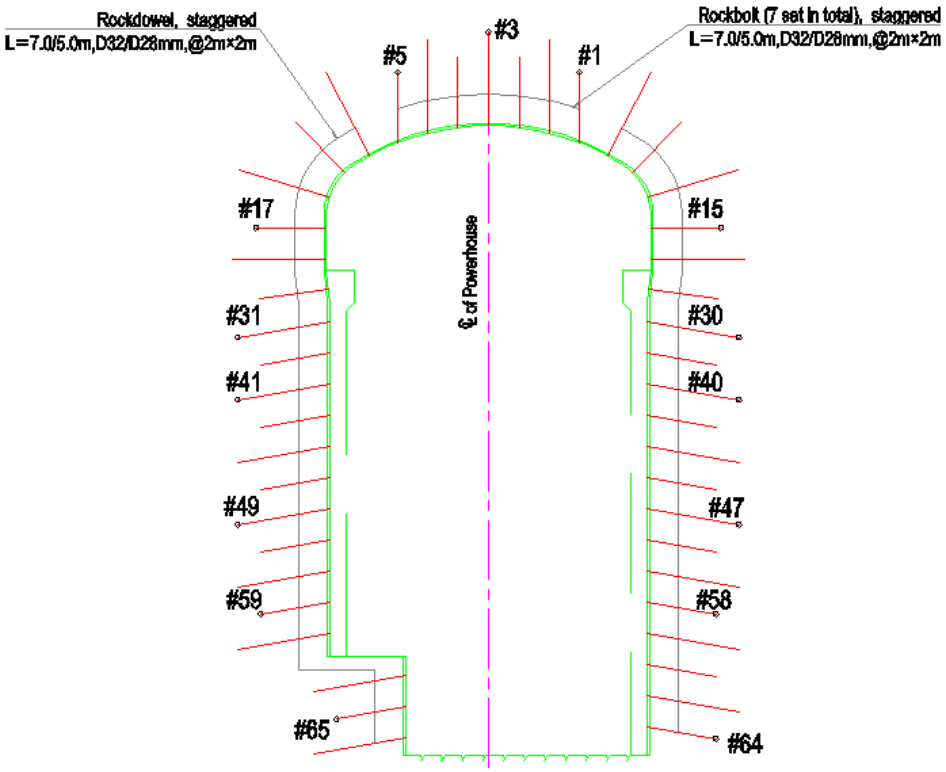


Figure 6.4-1 Typical rock dowels/bolts sketch

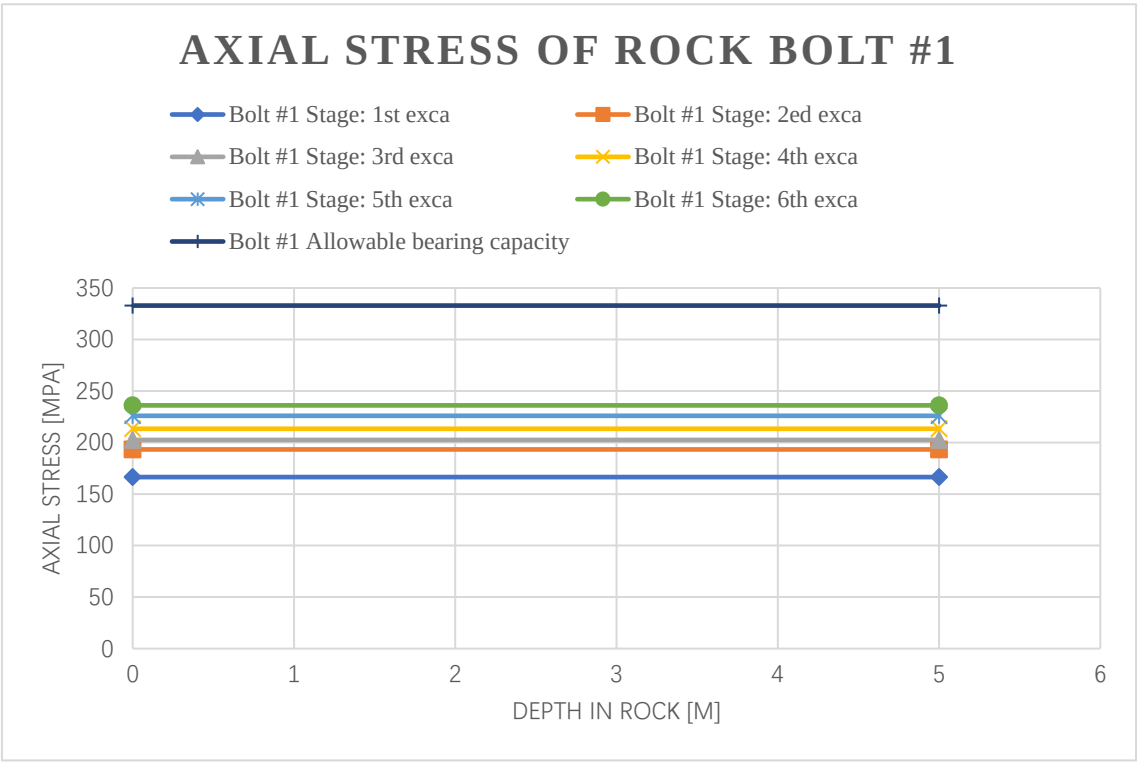


Figure 6.4-2 Axial stress of rock bolt #1 developing with excavation stages

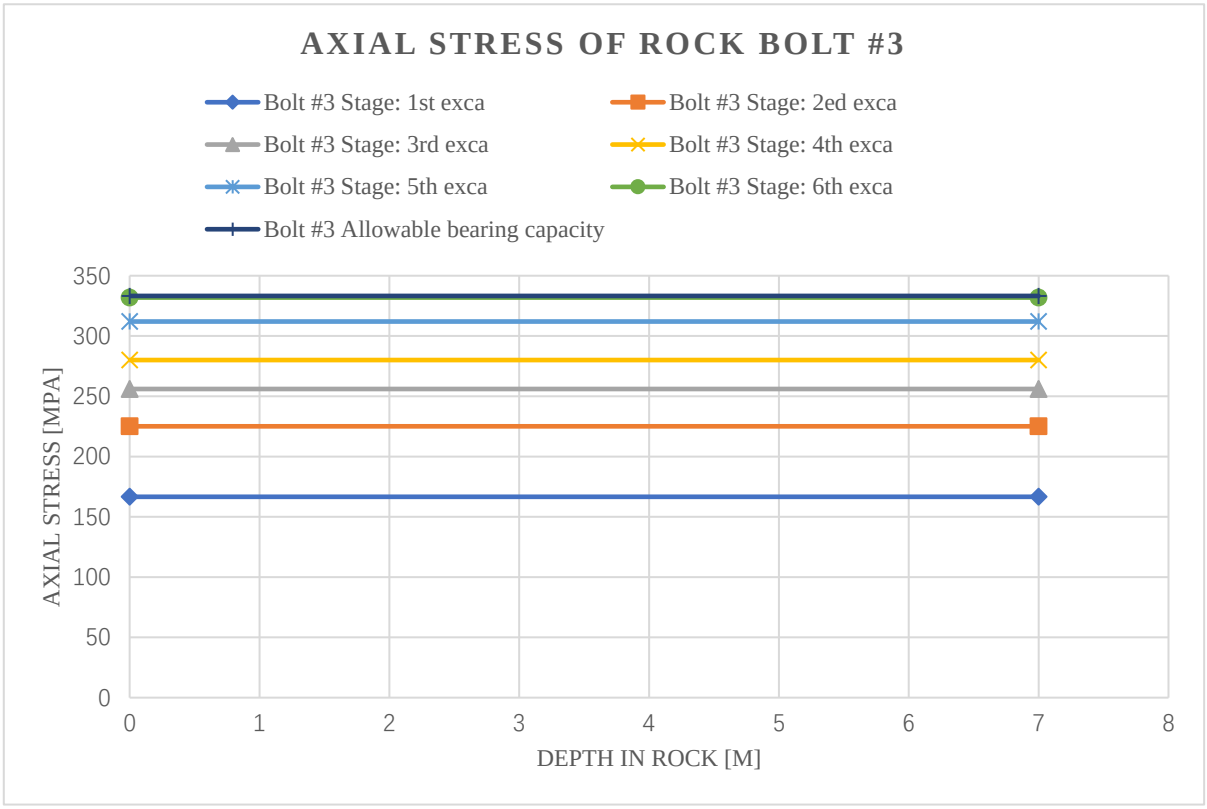

AXIAL STRESS OF ROCK BOLT #3
Bolt #3 Stage: 1st exca
Bolt #3 Stage: 2ed exca
Bolt #3 Stage: 3rd exca
Bolt #3 Stage: 4th exca
Bolt #3 Stage: 5th exca
Bolt #3 Stage: 6th exca
Bolt #3 Allowable bearing capacity
AXIAL STRESS [MPA]
DEPTH IN ROCK [M]

Figure 6.4-3 Axial stress of rock bolt #3 developing with excavation stages

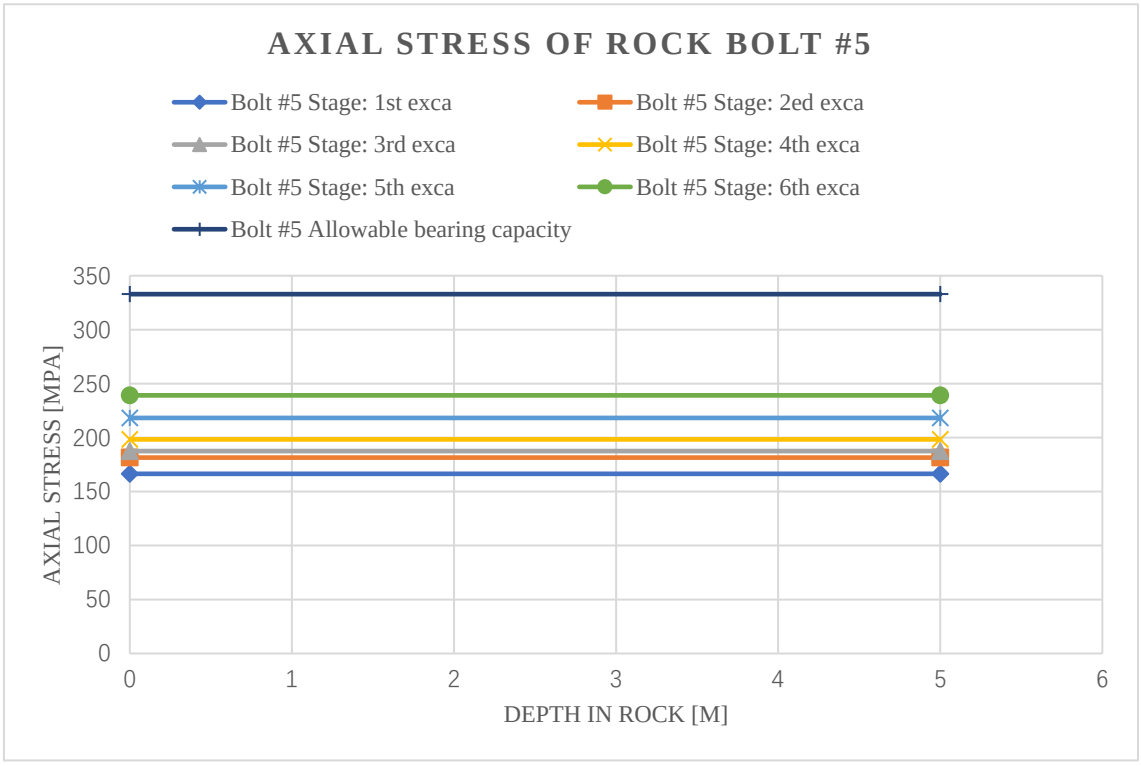

AXIAL STRESS OF ROCK BOLT #5
Bolt #5 Stage: 1st exca
Bolt #5 Stage: 2ed exca
Bolt #5 Stage: 3rd exca
Bolt #5 Stage: 4th exca
Bolt #5 Stage: 5th exca
Bolt #5 Stage: 6th exca
Bolt #5 Allowable bearing capacity
AXIAL STRESS [MPA]
DEPTH IN ROCK [M]

Figure 6.4-4 Axial stress of rock bolt #5 developing with excavation stages

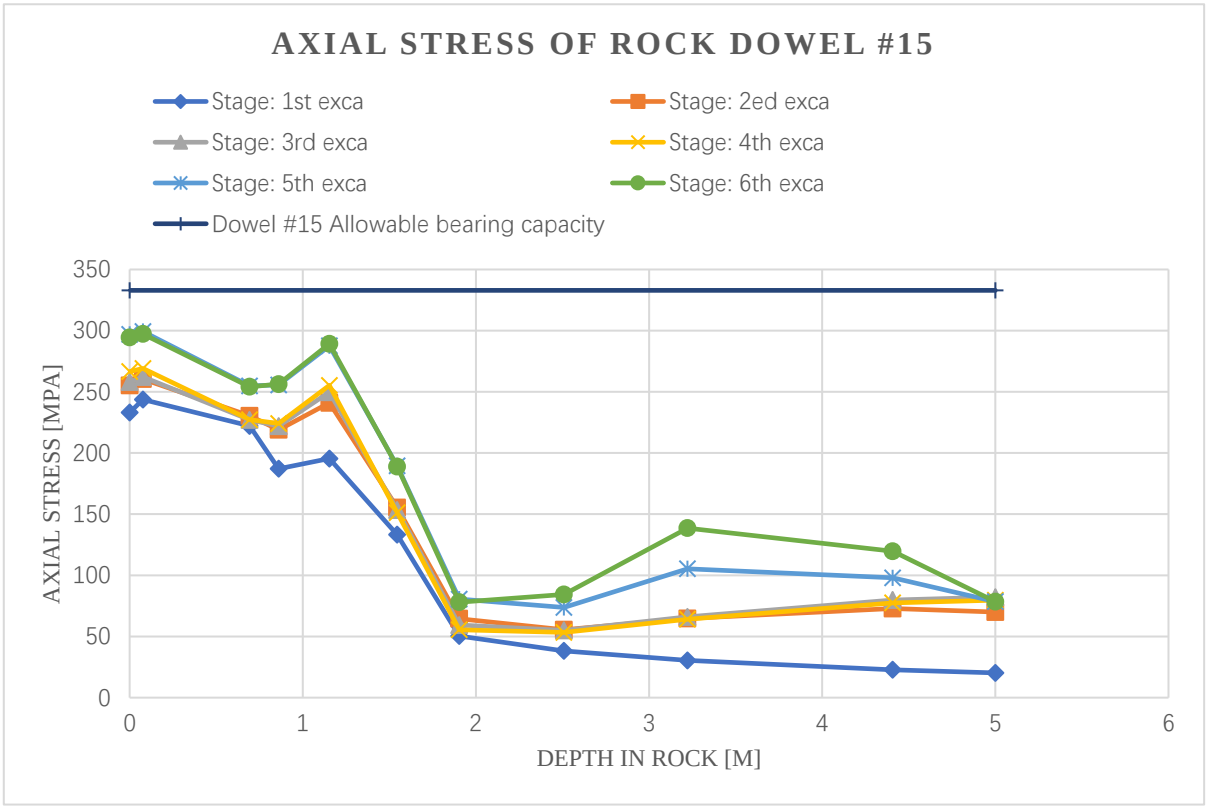


Figure 6.4-5 Axial stress of rock dowel #15 developing with excavation stages

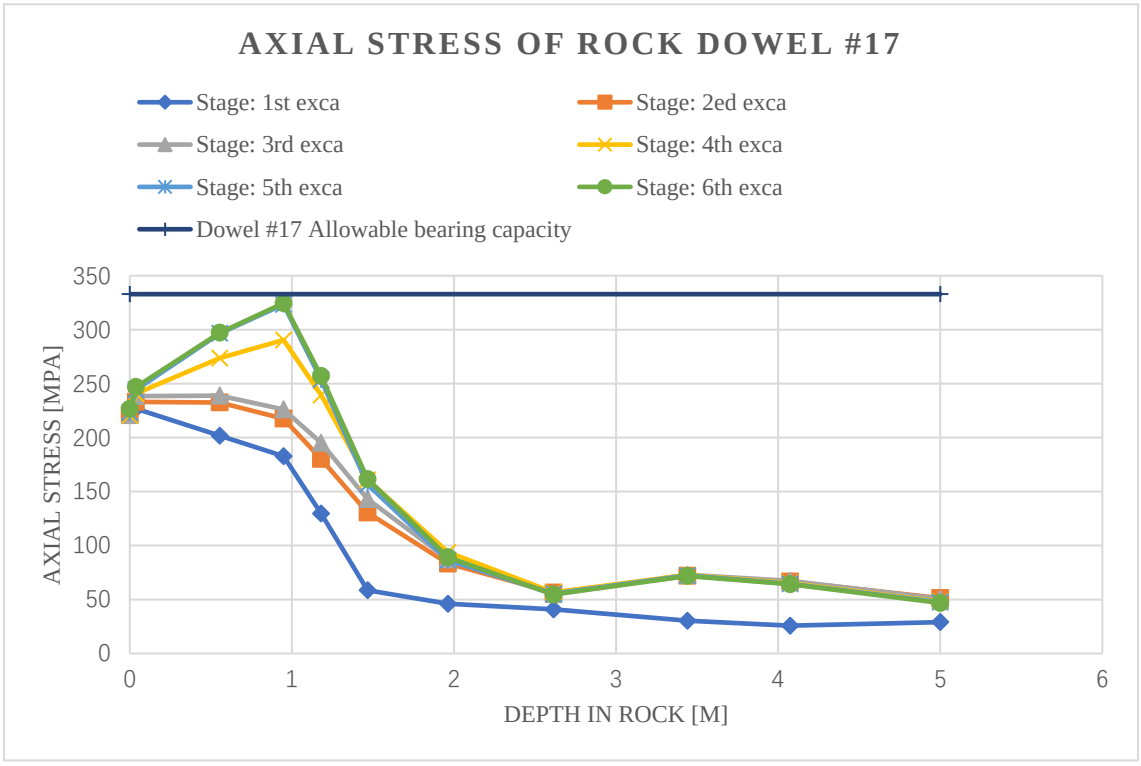


Figure 6.4-6 Axial stress of rock dowel #17 developing with excavation stages

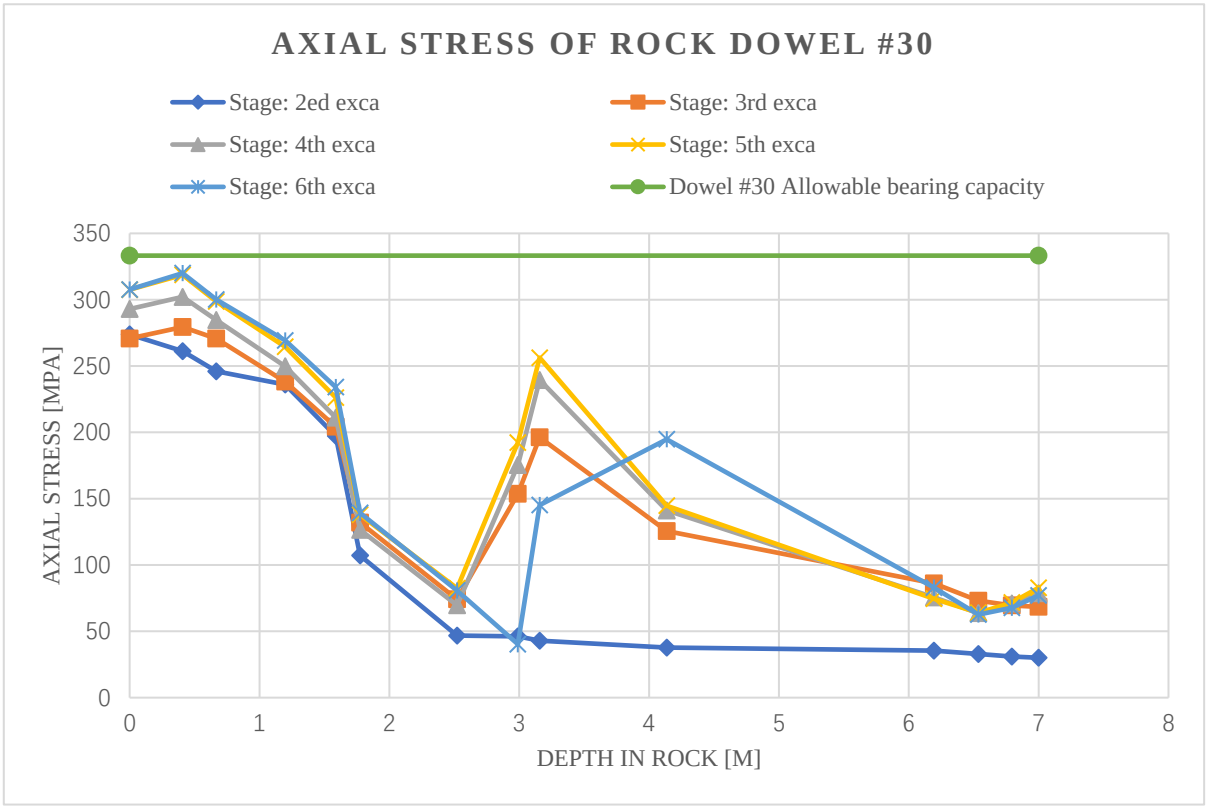


Figure 6.4-7 Axial stress of rock dowel #30 developing with excavation stages

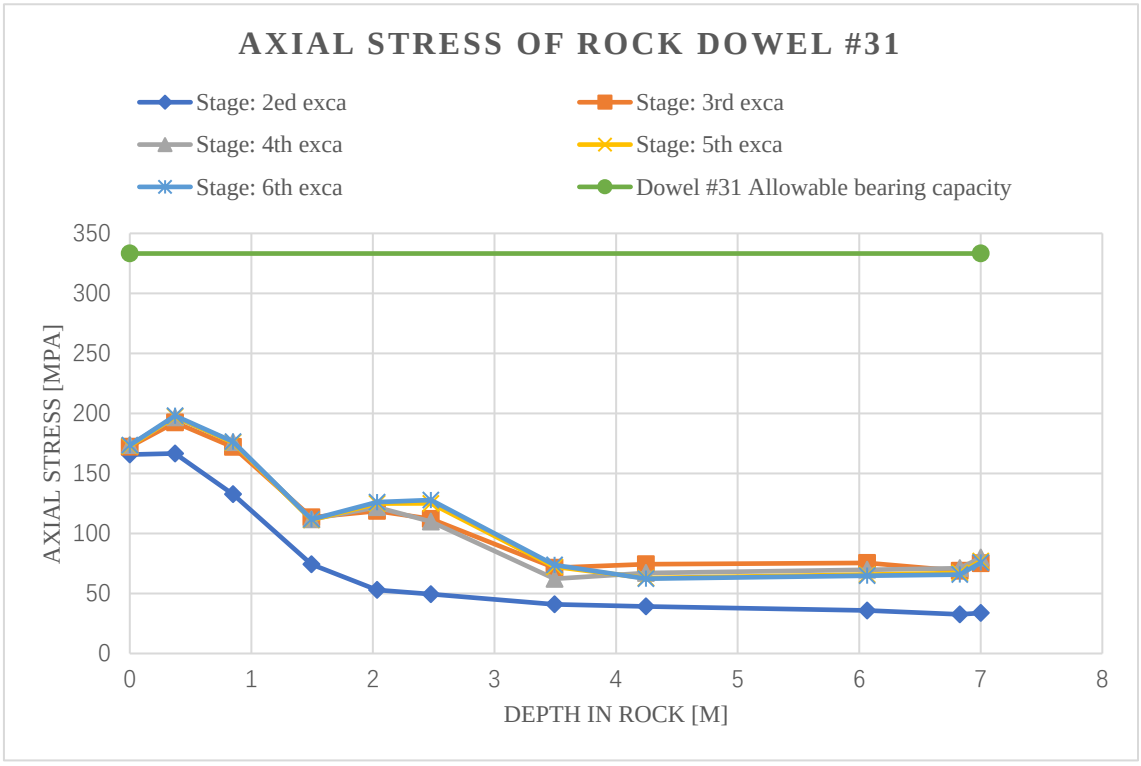


Figure 6.4-8 Axial stress of rock dowel #31 developing with excavation stages

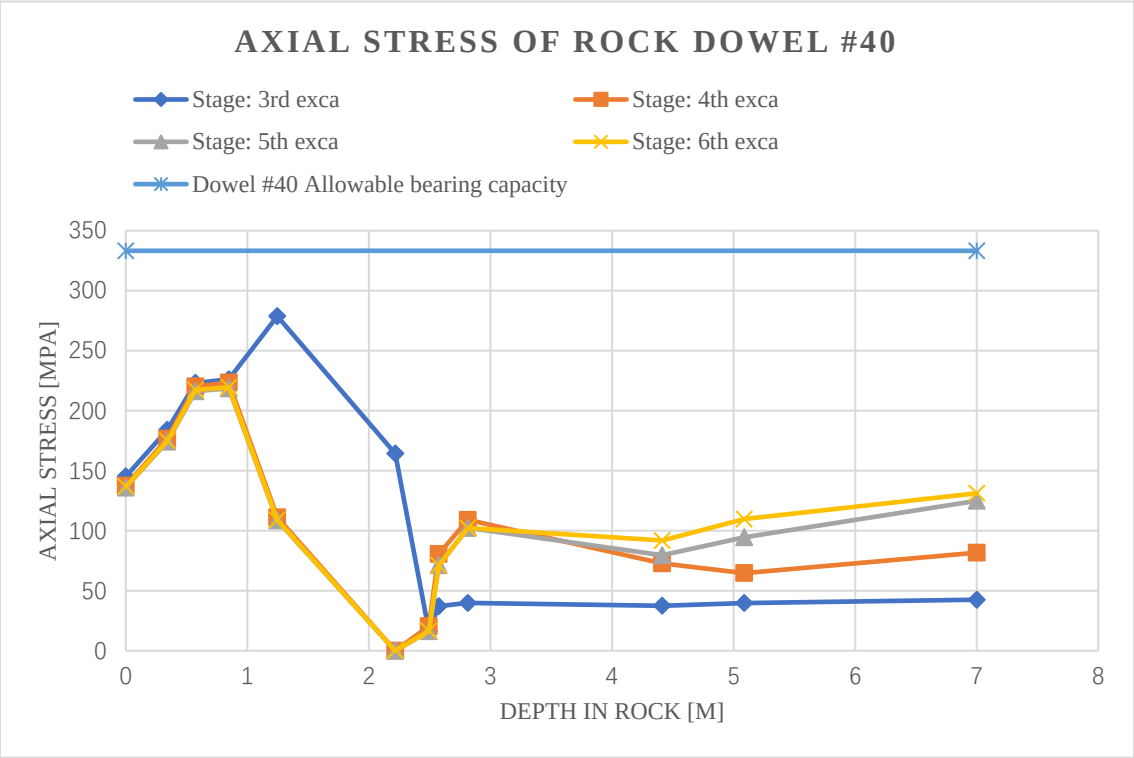


Figure 6.4-9 Axial stress of rock dowel #40 developing with excavation stages

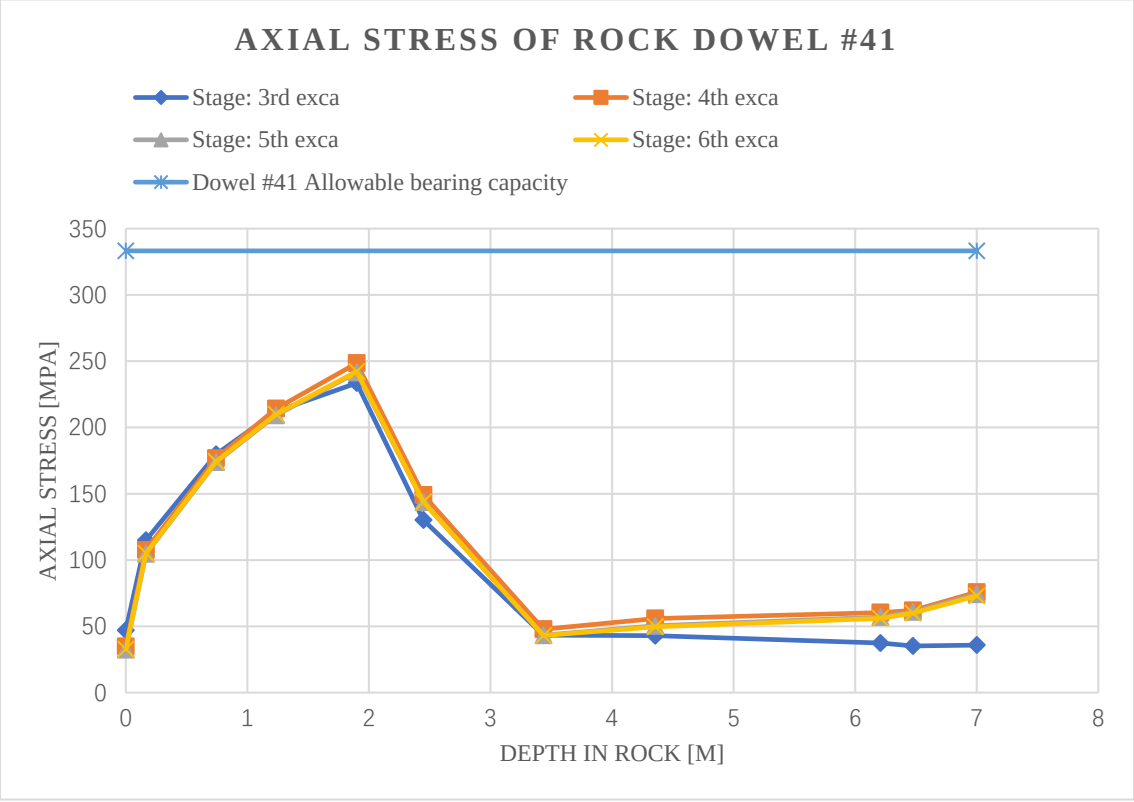


Figure 6.4-10 Axial stress of rock dowel #41 developing with excavation stage

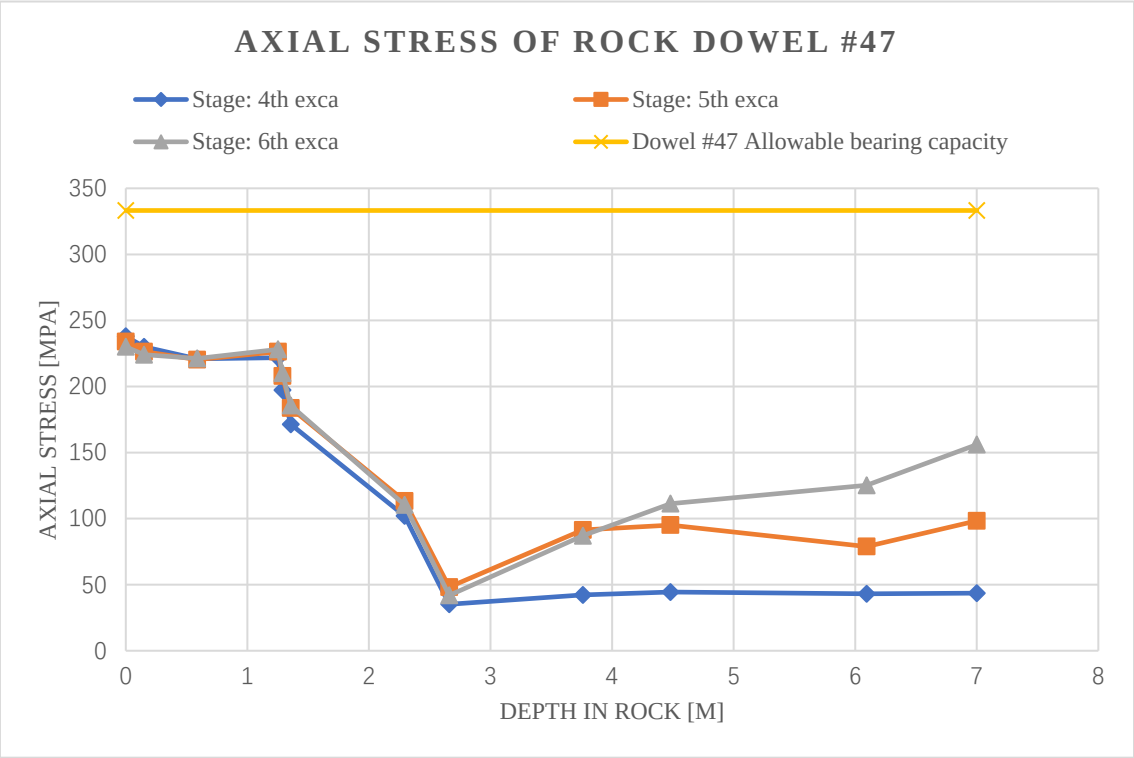


Figure 6.4-11 Axial stress of rock dowel #47 developing with excavation stages

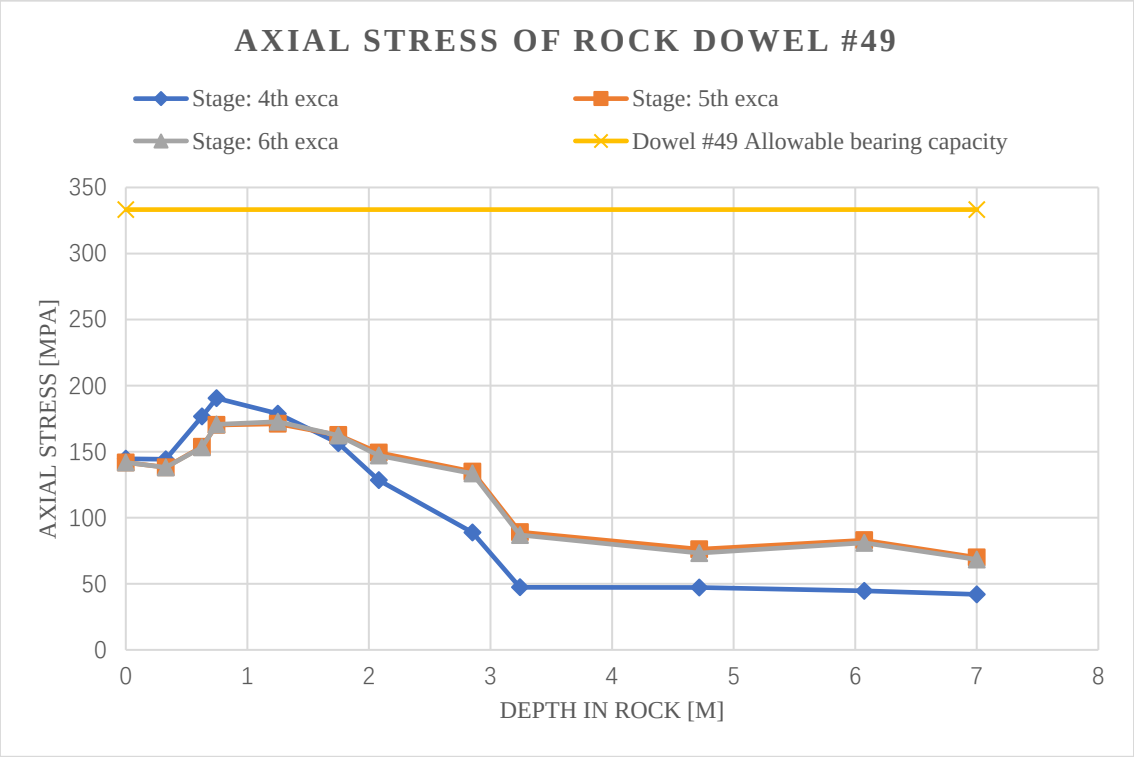


Figure 6.4-12 Axial stress of rock dowel #49 developing with excavation stages

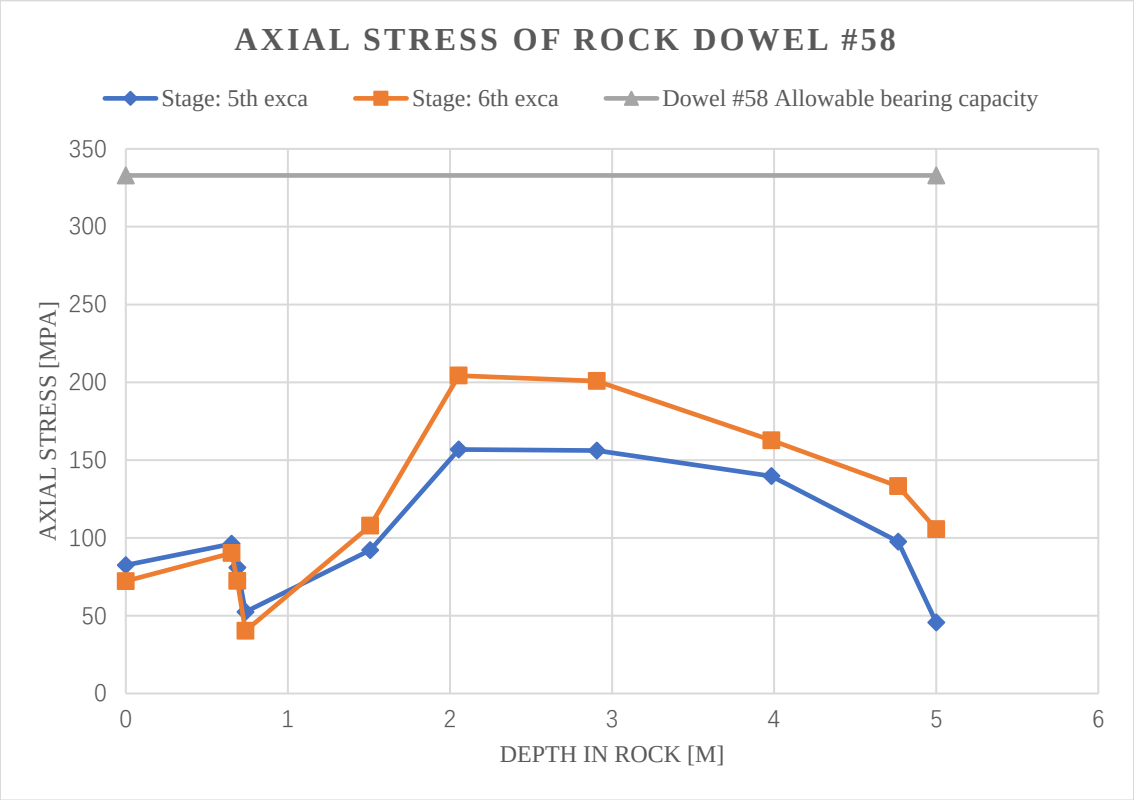


Figure 6.4-13 Axial stress of rock dowel #58 developing with excavation stages

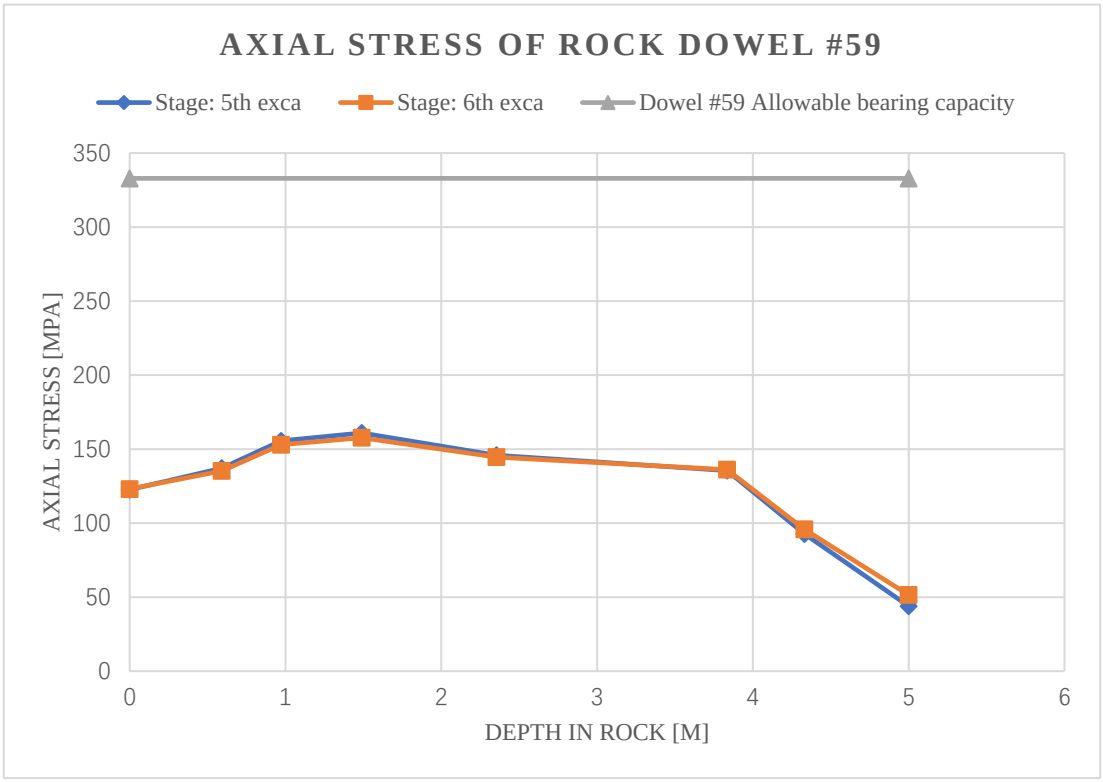


Figure 6.4-14 Axial stress of rock dowel #59 developing with excavation stages

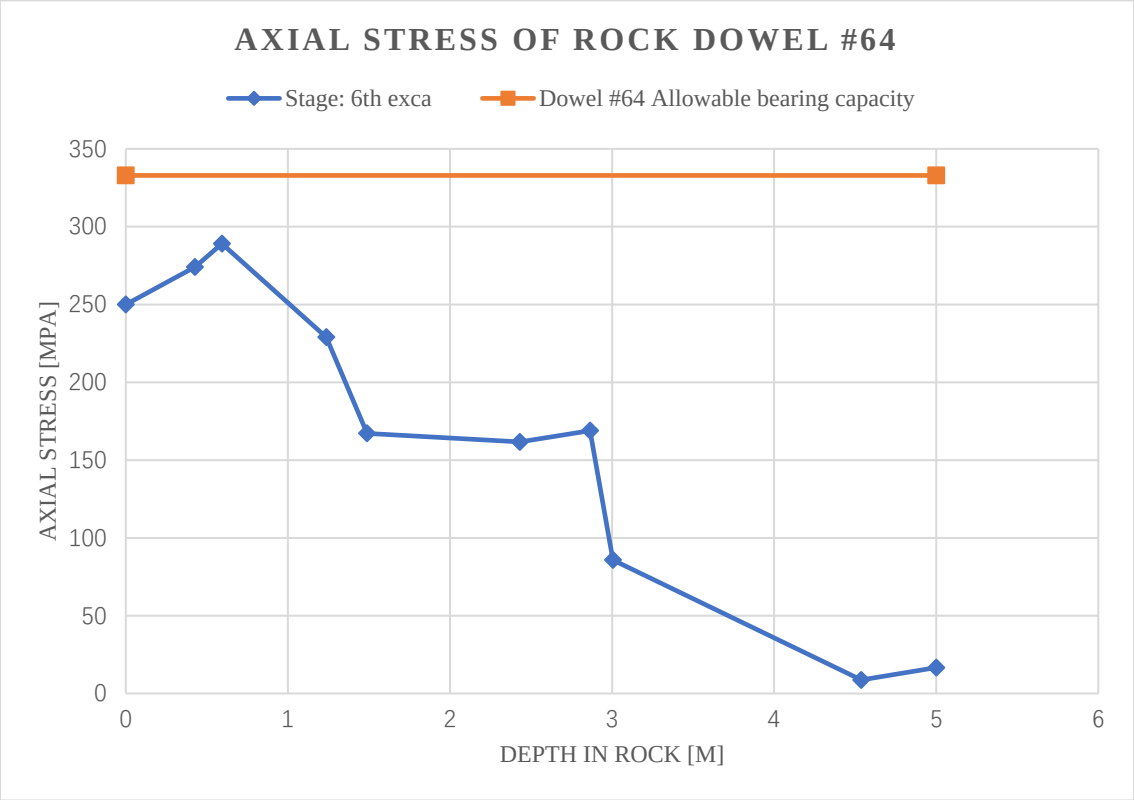


Figure 6.4-15 Axial stress of rock dowel #64 developing with excavation stages

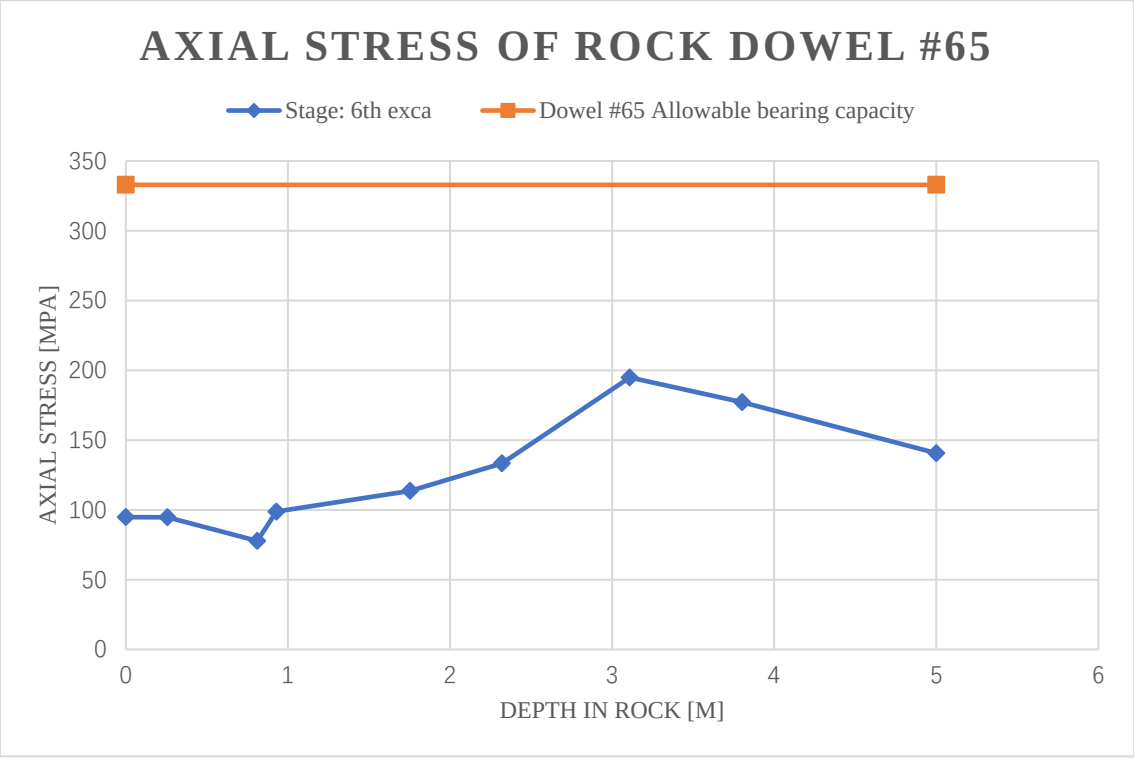


Figure 6.4-16 Axial stress of rock dowel #65 developing with excavation stages

6.5 Rock class III (Basic design supporting scheme)

According to bid documents, annexes, section VII, annex 5, 07 powerhouse drawings, supports of the powerhouse and transformer caverns is as below and shown in Figure 6.5-1.

(1)Powerhouse cavern

Roof: rock dowels, φ32mm, spacing 1.5m, L=8.0m.

Side wall: rock dowels, φ32mm, spacing 1.5m, L=12.0m.

(2)Transformer cavern

Roof: rock dowels, φ32mm, spacing 1.5m, L=8.0m.

Side wall: rock dowels, φ32mm, spacing 1.5m, L=12.0m.

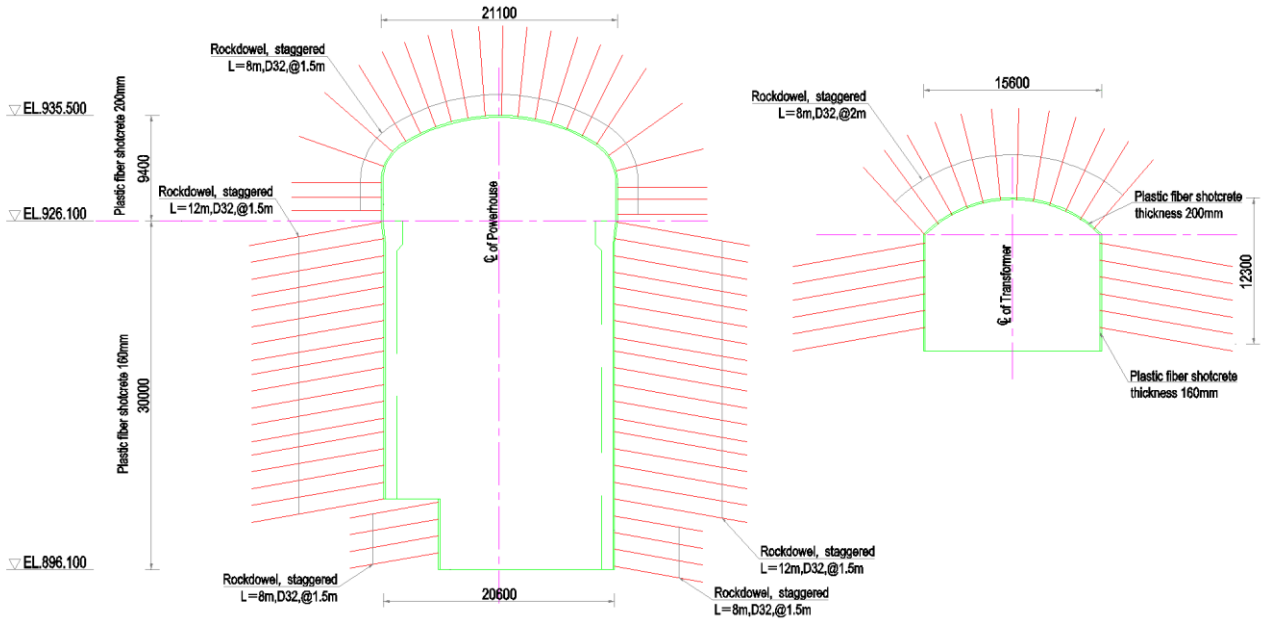


Figure 6.5-1 Basic design supports of powerhouse and transformer caverns (rock type III)

Calculation result is as shown in Figures 6.5-2~6.5-4.

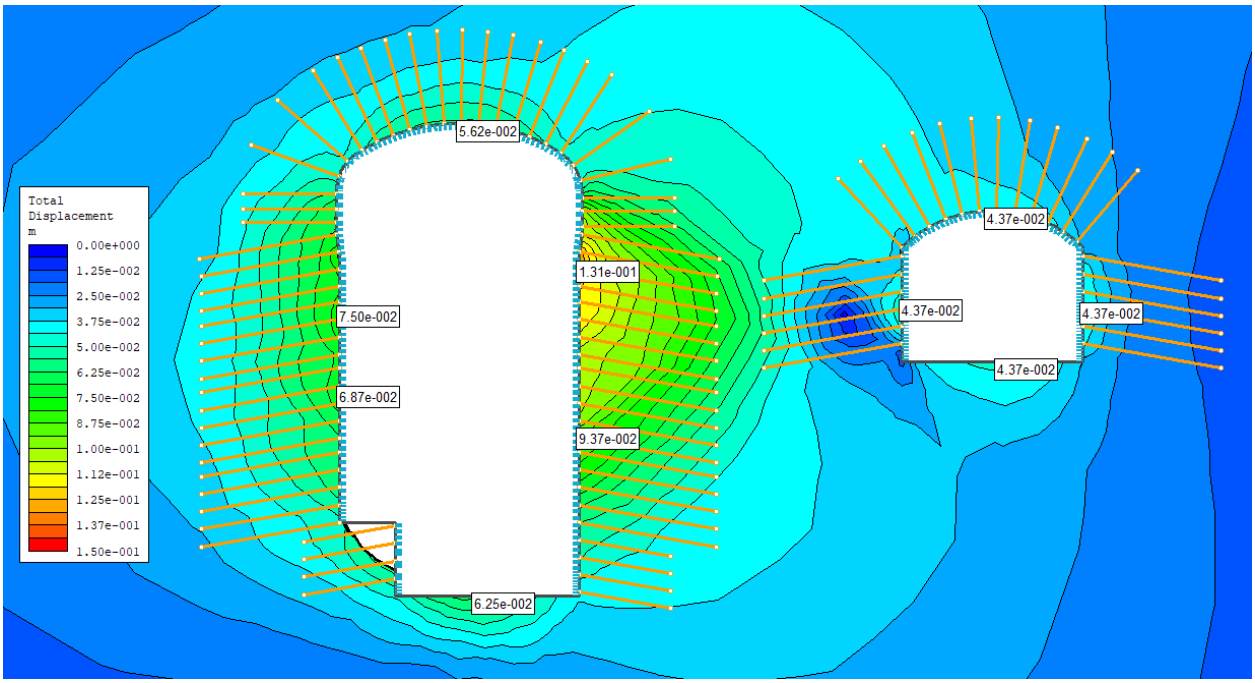


Figure 6.5-2 Total displacement after support installation (Rock Class III)

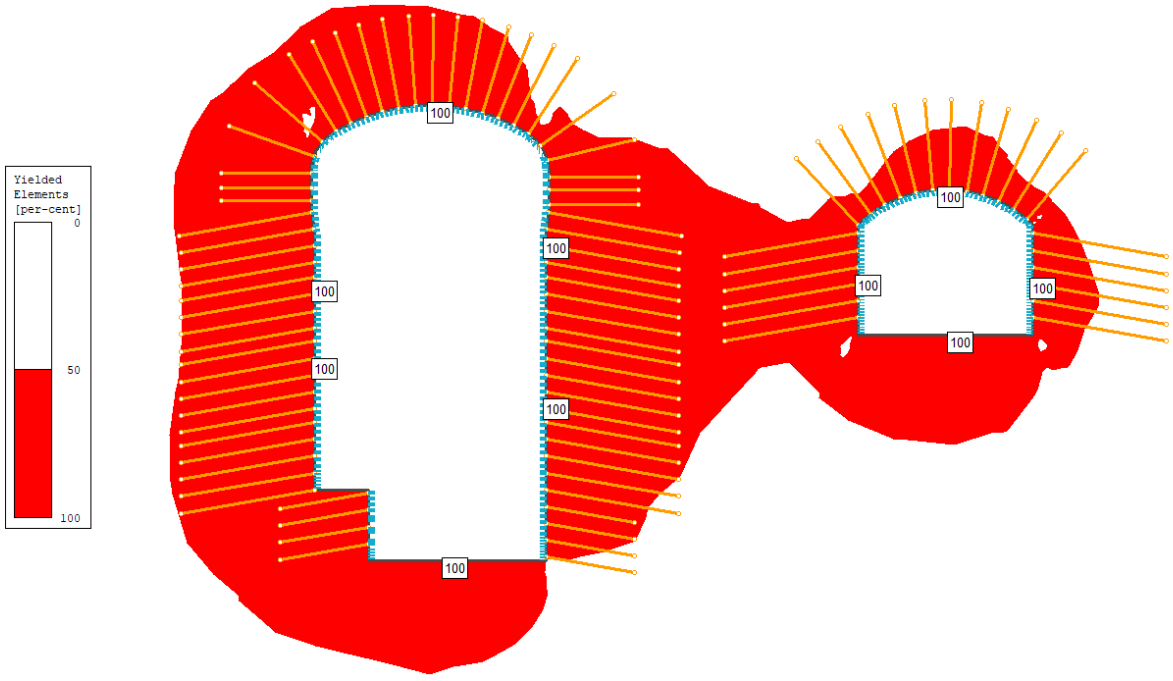


Figure 6.5-3 Plastic zone after support installation (Rock Class III)

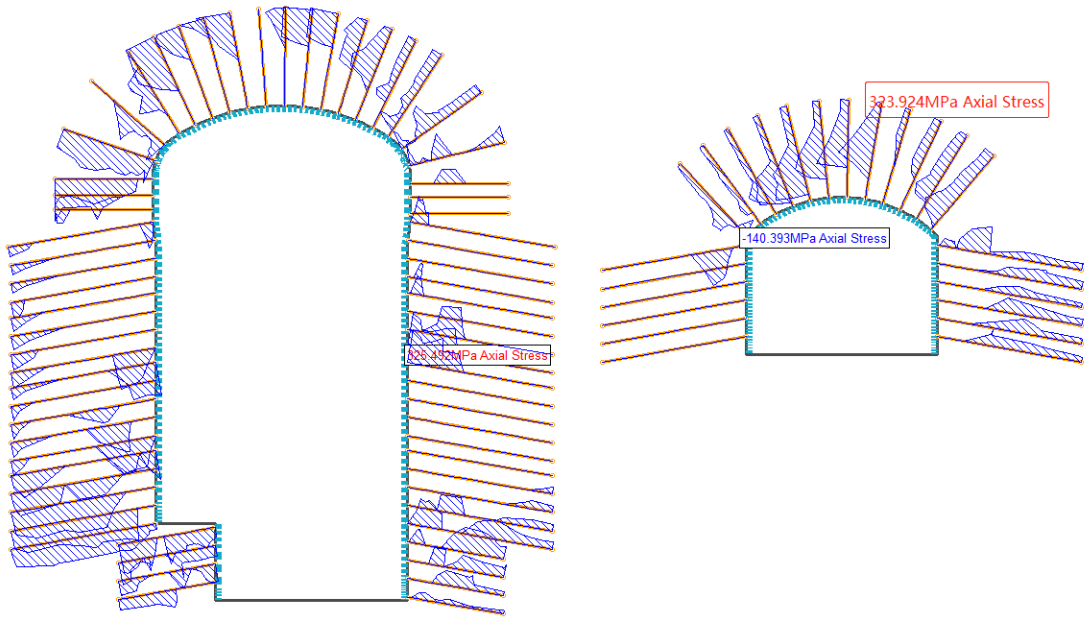


Figure 6.5-4 Axial stress of rock dowels after support installation (Rock Class III)

6.6 Rock class III (Prop supports)

The proposed supports in this stage are almost the same as that proposed in basic design stage except supports in the central portion of the cavern crowns, where, rock bolts are proposed to supersede the rock dowels and vertically arranged.

The proposed supports in this stage are as shown in Figure 6.6-1.

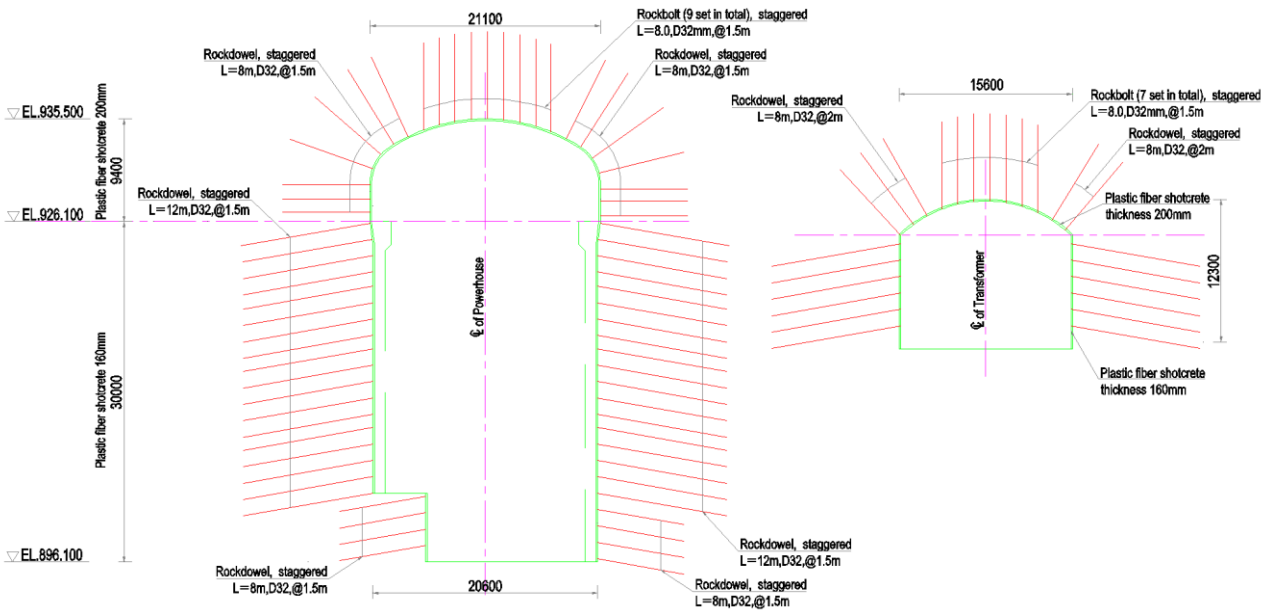


Figure 6.6-1 Prop supports of powerhouse and transformer caverns (rock type III)

Calculation result is as shown in Figures 6.6-2~6.6-4.

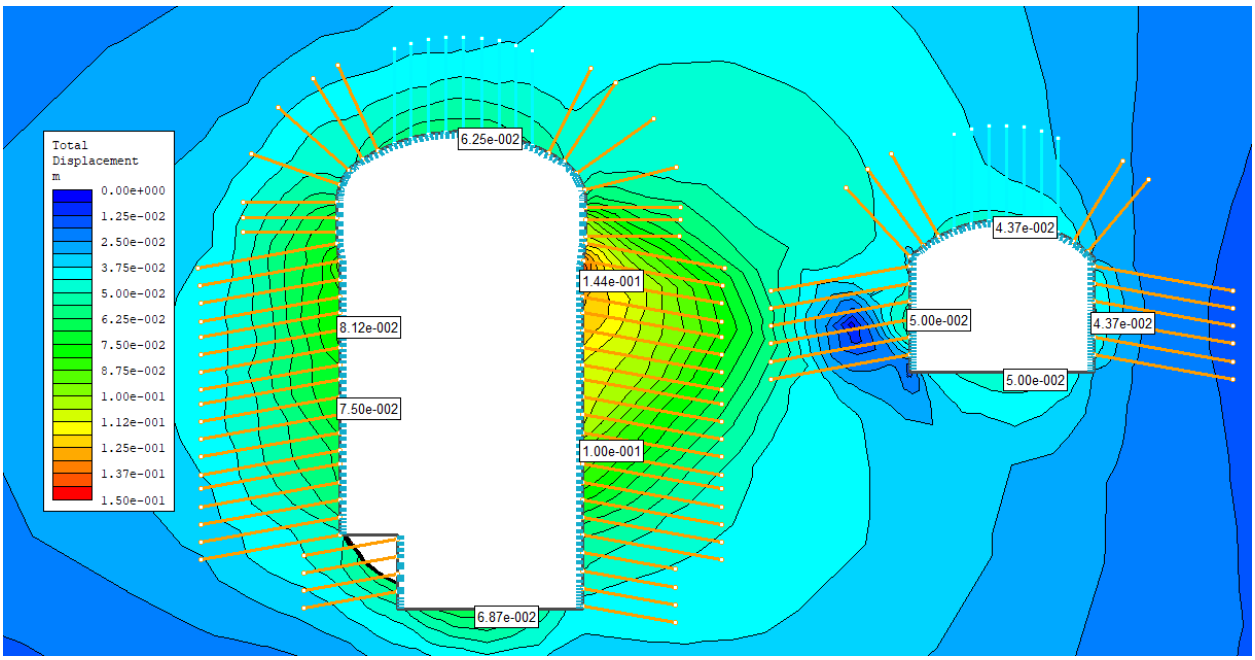


Figure 6.6-2 Total displacement after support installation (Rock Class III)

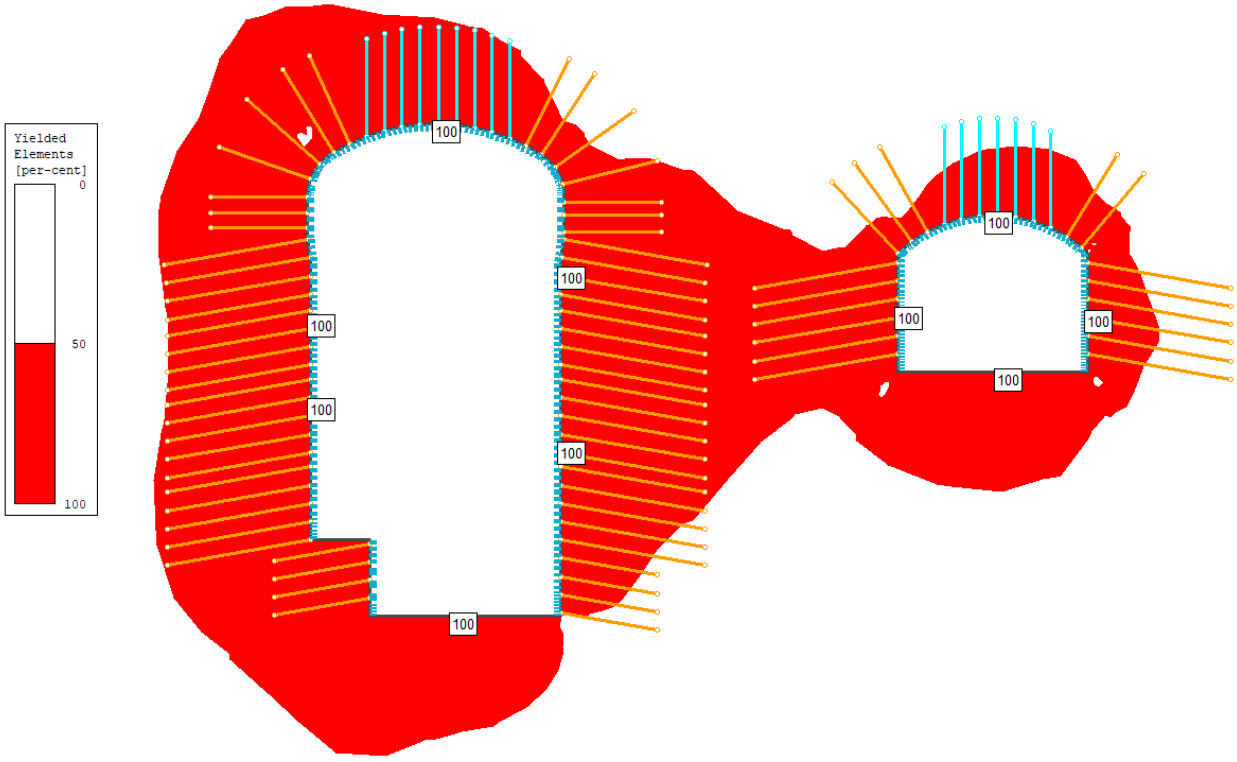


Figure 6.6-3 Plastic zone after support installation (Rock Class III)

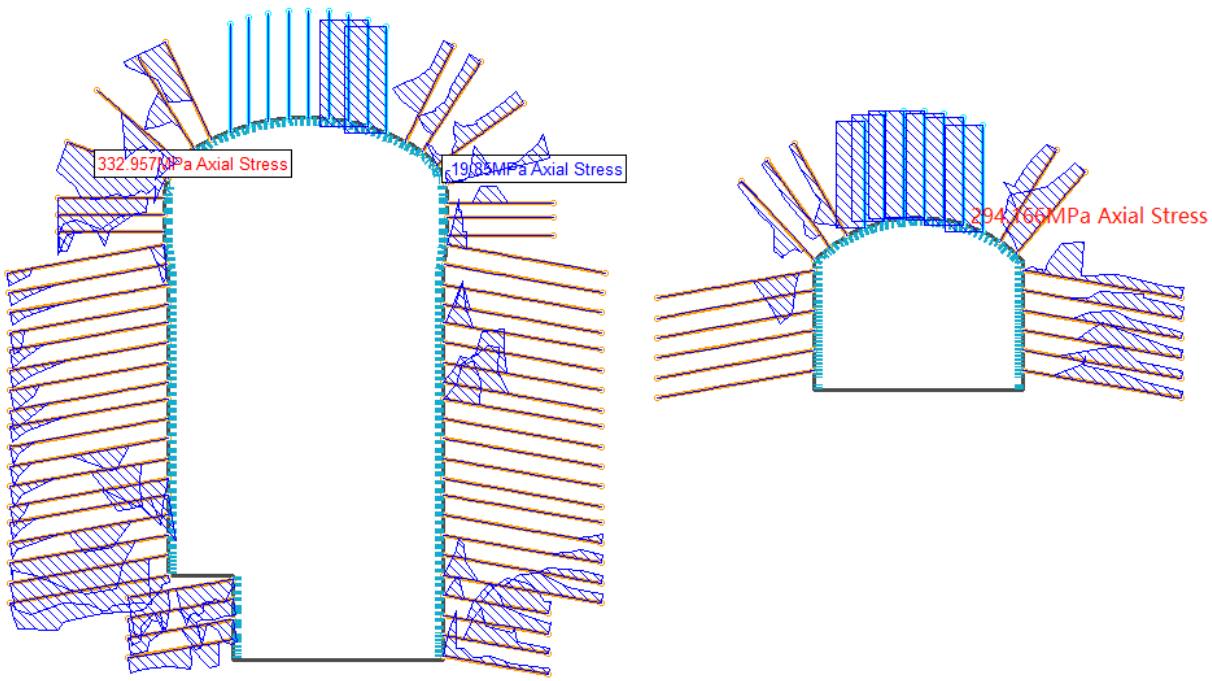


Figure 6.6-4 Axial stress of rock dowels/rock bolts after support installation (Rock Class III)

7 Wedge Analysis

7.1 Discontinuity Input Data

According to the geological logging of the ventilation tunnel and the main access tunnel of the power house and the geological mapping around the power house, a total of 615 joints are counted. Most joints are closed, a few are slightly open, there is no filling between joints, and a few joints are filled with a small amount of calcium film, rock powder and rock debris.

According to the statistical analysis of Dips software, four groups of joints are mainly developed in the powerhouse area, and the joint characteristics are as follows:

There are 4 groups joints may distribute in the powerhouse surrounding rock, as is shown in Table 7-1~7-2. The stereographic projection of these joints in rock mass in shown in Figure 7-1~7-4. The Mechanical parameter of joints is shown in Table 7-3.

Table 7-1 Features of joints within the powerhouse cavern surrounding rock

Joint NO.	Dip Direction	Dip	powerhouse Direction(Trend)
J1(foliation)	5°	25°	N93°
J2	145°	70°	
J3	200°	72°	
J4	30°	70°	

Table 7-2 Description of joints within the powerhouse cavern surrounding rock

NO.	Type	Occurrence（dip direction/dip）	Structural plane
J1	Foliation	355-10/15-30	spacing is 0.1-0.3m, the local spacing is 0.01-0.05m, the extension > 2m, the surface is straight and rough
J2	joint	135-150/60-75	spacing is 0.5-2m, the extension 2-8m, the surface is straight and rough
J3	joint	198-208/68-75	spacing is 2-5m, the extension 2-8m, the surface is straight and rough
J4	joint	20-45/65-72	spacing is 0.5-2m, the extension 0.5-4m, the surface is straight and rough

Table 7-3 Mechanical parameter of joints within the powerhouse cavern surrounding rock

JONIT TYPE	C	Φ
	（MPa）	（°）
Foliation(J1)	0.20	35.0
lithoclasts cemented (J2~J6)	0.15	28.8

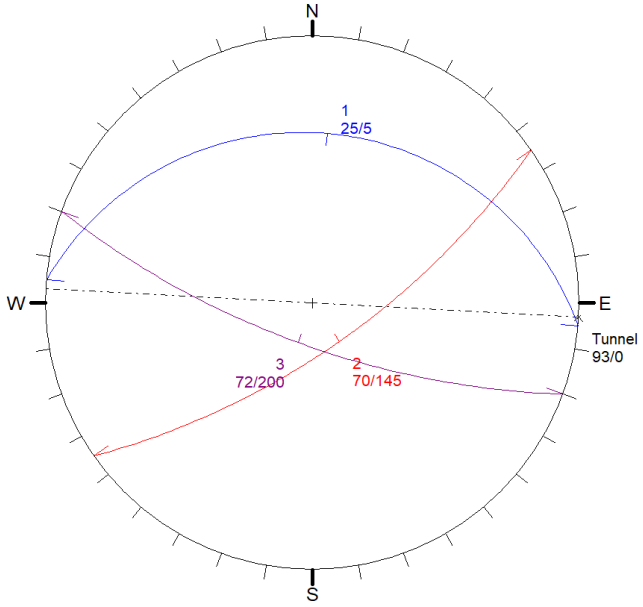


Figure 7-1 Stereographic projection of the joins J1/J2/J3

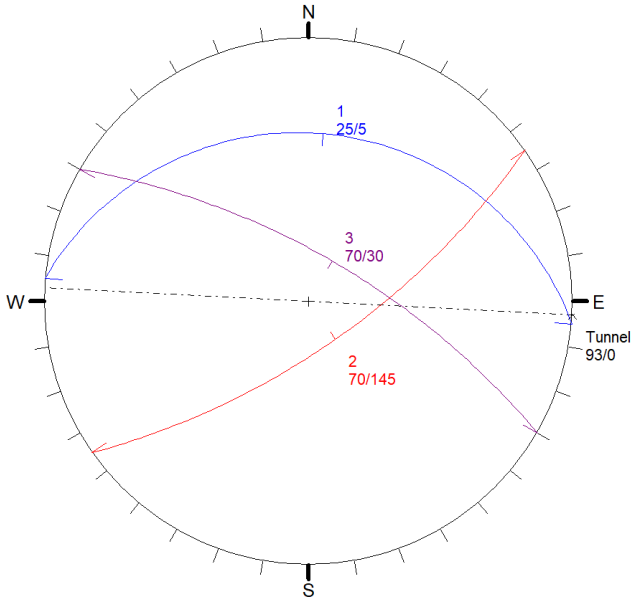


Figure 7-2 Stereographic projection of the joins J1/J2/J4

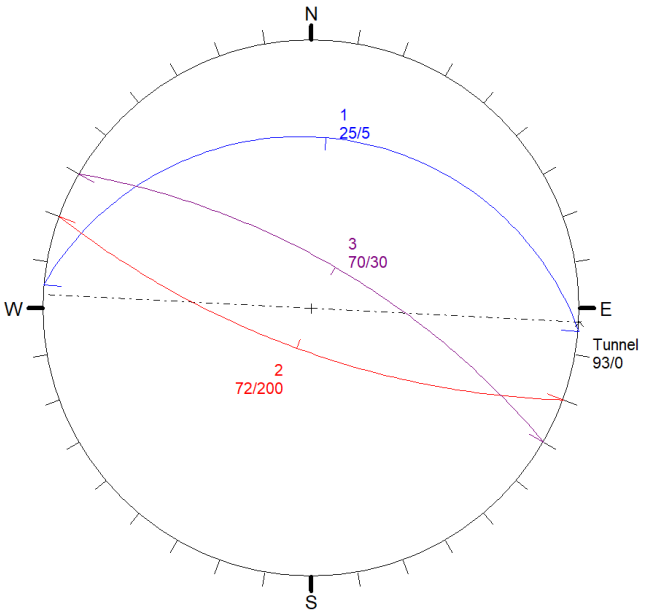


Figure 7-3 Stereographic projection of the joins J1/J3/J4

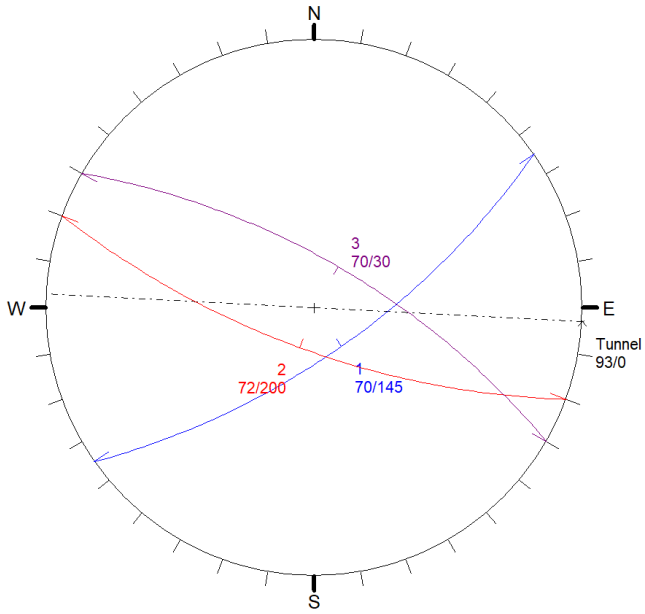


Figure 7-4 Stereographic projection of the joins J2/J3/J4

7.2 Wedge Stability Analysis

7.2.1 Tetrahedral wedges analysis

According to the wedge stability analysis, 4 groups of potential wedges may occur in the excavation periods, which are shown in Table 7-4.

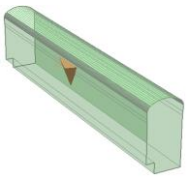
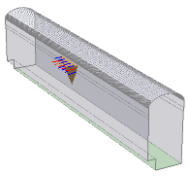
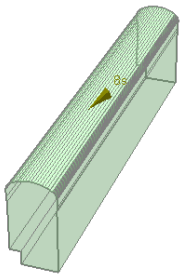
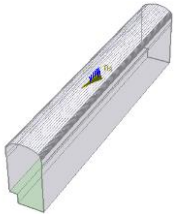
Principle for selection of potential wedge sizes: Wedge size is limited by either apex-height (= max. extent of plastic zone), or persistence of respective discontinuities, whatever produces smaller wedges.

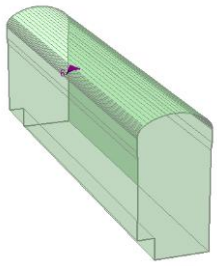
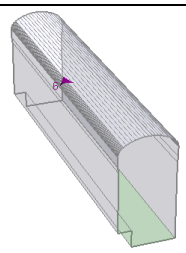
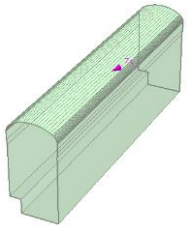
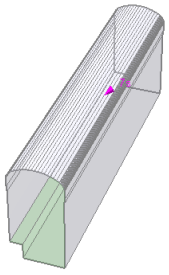
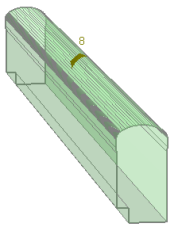
Persistence of discontinuities is generally 3m~5m, only few more than 5m. The spacing of foliation is generally 0.3m~1.0m, only few up to 1.0m~2.0m.

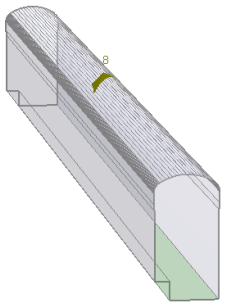
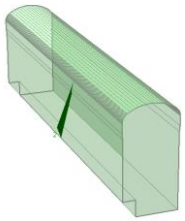
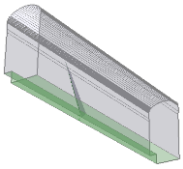
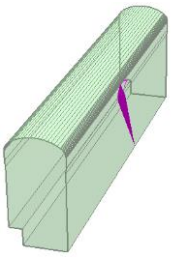
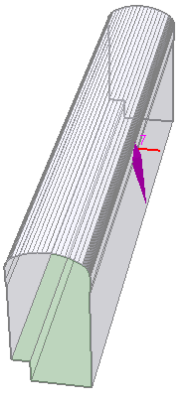
Plastic zone: according to calculation result, its depth is less than 8.0m for class II surrounding rock.

Based on the above information, the potential wedges of interest are those with apex height no more than 5m for side wall, and 2m for cavern roof.

Table 7-4 Instability block search statistics of Powerhouse

No.	Fissure set number	Block volume (m^3)	Apex height (m)	Safety factor	Development position	Stability	Graphical presentation of block
1	J1/J2/J3	225.04	4.2	1.375	Upper left side wall	Unstable	
After pattern supports				2.79		Stable	
2	J1/J2/J3	39.605	2.5	0	Crown	Unstable	
After pattern supports				7.12		Stable	

No.	Fissure set number	Block volume (m^3)	Apex height (m)	Safety factor	Development position	Stability	Graphical presentation of block
3	J1/J2/J4	1.45	0.66	0	Upper left side wall	Unstable	
After pattern supports				22.74		Stable	
4	J1/J2/J4	5.78	2.0	0	Upper left side wall	Unstable	
After pattern supports				13.55		Stable	
5	J1/J3/J4	36.9	2.19	0	Crown	Unstable	

No.	Fissure set number	Block volume (m^3)	Apex height (m)	Safety factor	Development position	Stability	Graphical presentation of block
After pattern supports				7.358		Stable	
6	J2/J3/J4	56.9	1.79	0	Lower left side wall	Unstable	
After pattern supports				2.22		Stable	
7	J2/J3/J4	74.7	1.78	0	Lower right side wall	Unstable	
After pattern supports				2.2		Stable	

7.2.2 Prismatic wedges

As shown in the hemispherical plot below, prismatic wedges (red-shaded in plot) are developing in the cavern roof. They are formed by the Joint Sets 1,2,3 and 4, and detaching from cavern roof through the foliation jointing, which must be assumed to have nil tensile strength.

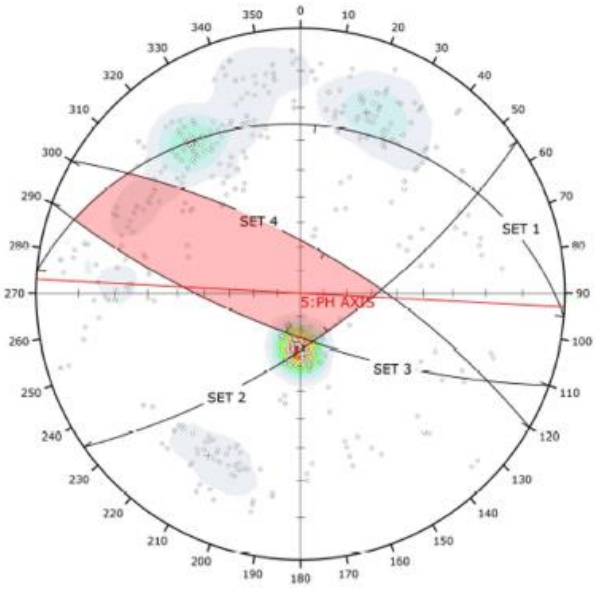


Figure 7-5 Contour and pole plot

It is assumed that the following blocks may be formed by intersection of 4 discontinuities and foliation.

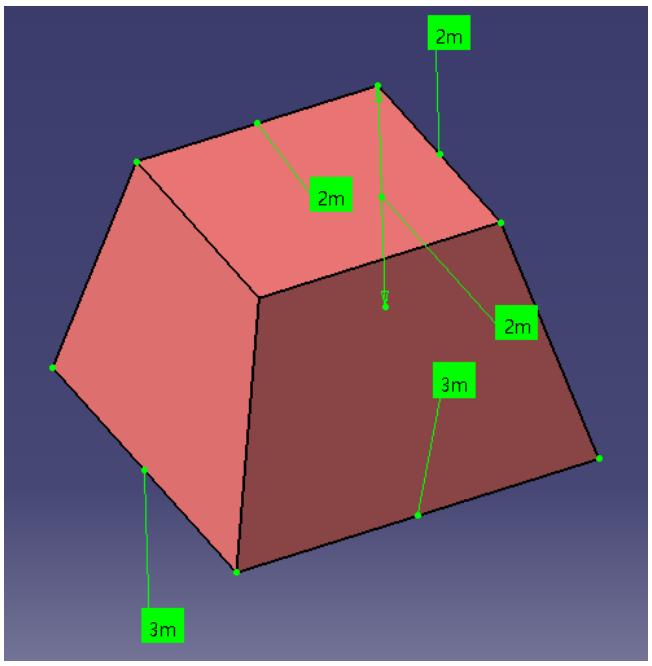


Figure 7-6 Potential prismatic wedge in the cavern roof

The top surface size is 2mx2m (Rectangular simulation), the bottom surface size is 3mx3m, and the apex height of block is about 2m. The wedge volume is about 12.667 m^3, and the weight is 34.2t, the single rock bolt allowable bearing capacity is about 30.8t (Dia.28mm), 40.2t (Dia.32mm).

According to the pattern rock bolts/dowels spacing, there are 4 pcs of rock bolts/dowels into the block. Without considering the shear strength of the discontinuities, safety factor of the block is : resistance of bolt/ self weight of the bock=(30.8x2+40.2x2)/34.2=4.15. After pattern supports, the safety factor of the block can meet the requirement of the minimum safety factor of 2.0.

8 Conclusions

(1) For rock class II with basic design supports, rock bolts are quite outcropped the plastic zone, rock bolt stress at deeper section is relatively smaller than allowable stress, showing that the supports in the basic design were overdesigned and can be optimized. Contractor proposes to reduce the rock bolt length in his detail design.

(2) For rock class II with proposed supports, maximum crown and sidewall displacement is 12.5mm and 26.2mm respectively, which accounts for 0.06% and 0.1% of powerhouse span; the maximum rock dowel tensile stress is 330MPa, which is less than its allowable value. Therefore, the proposed supports are appropriate. Maximum crown and sidewall displacement is 12.5mm and 15mm respectively, which accounts for 0.08% and 0.1% of transformer span; the maximum rock dowel tensile stress is 304MPa, which is less than its allowable value. Therefore, the proposed supports are appropriate.

(3) For rock class III with proposed supports, maximum crown and sidewall displacement is 62.5mm and 144mm respectively, which accounts for 0.3% and 0.69% of powerhouse span; the maximum rock dowel tensile stress is 333MPa, which is less than allowable strength of rock dowel and rock bolt. Maximum crown and sidewall displacement is 43.7mm and 50mm respectively, which accounts for 0.11% and 0.32% of transformer span; the maximum rock dowel tensile stress is 294MPa, which is less than allowable strength of rock dowel and rock bolt. Therefore, the proposed supports are appropriate. The difference between the proposed scheme and basic design scheme lies in the supports at the crown, in the proposed scheme, rock bolts in vertical direction are designed to replace the rock dowels designed in the basic scheme.

(4) For wedges potentially exists in the cavern crown and sidewall, UNWEDGE analysis is carried out. The calculation results show that all of the wedges will be stable after pattern supports.

(5) During tunneling excavation of the powerhouse and transformer caverns, reasonable excavation and supporting sequence, as well as excavation height and advance, shall be followed to avoid failure of the potential unstable blocks.

9 Annex-Joints Survey Report of Powerhouse Zone

JOINTS SURVEY REPORT OF POWERHOUSE ZONE

In order to comprehensively evaluate the joint characteristics of the Undergroung Powerhouse（PH）area，The joints of the plant slope，Ventilation tunnel（VT） and Main traffic tunnel （MAT）were investigated.

The field investigation found that the wedge shape failure of the slope in the PH area is mainly caused by the combination of foliation joints and several sets of shear joints with high steep angle（Figure 1.Figure 2）.

It is speculated that the wedge on the roof of the underground powerhouse after excavation, and the failure form is similar to the outside slope.

Figure 1　Wedge of　VT　tunnel　zone slope

Figure 2　Wedge of　MAT tunnel zone slope

Statistics table 1

Joint Measurement Sheet Left side slope of VT 2019.

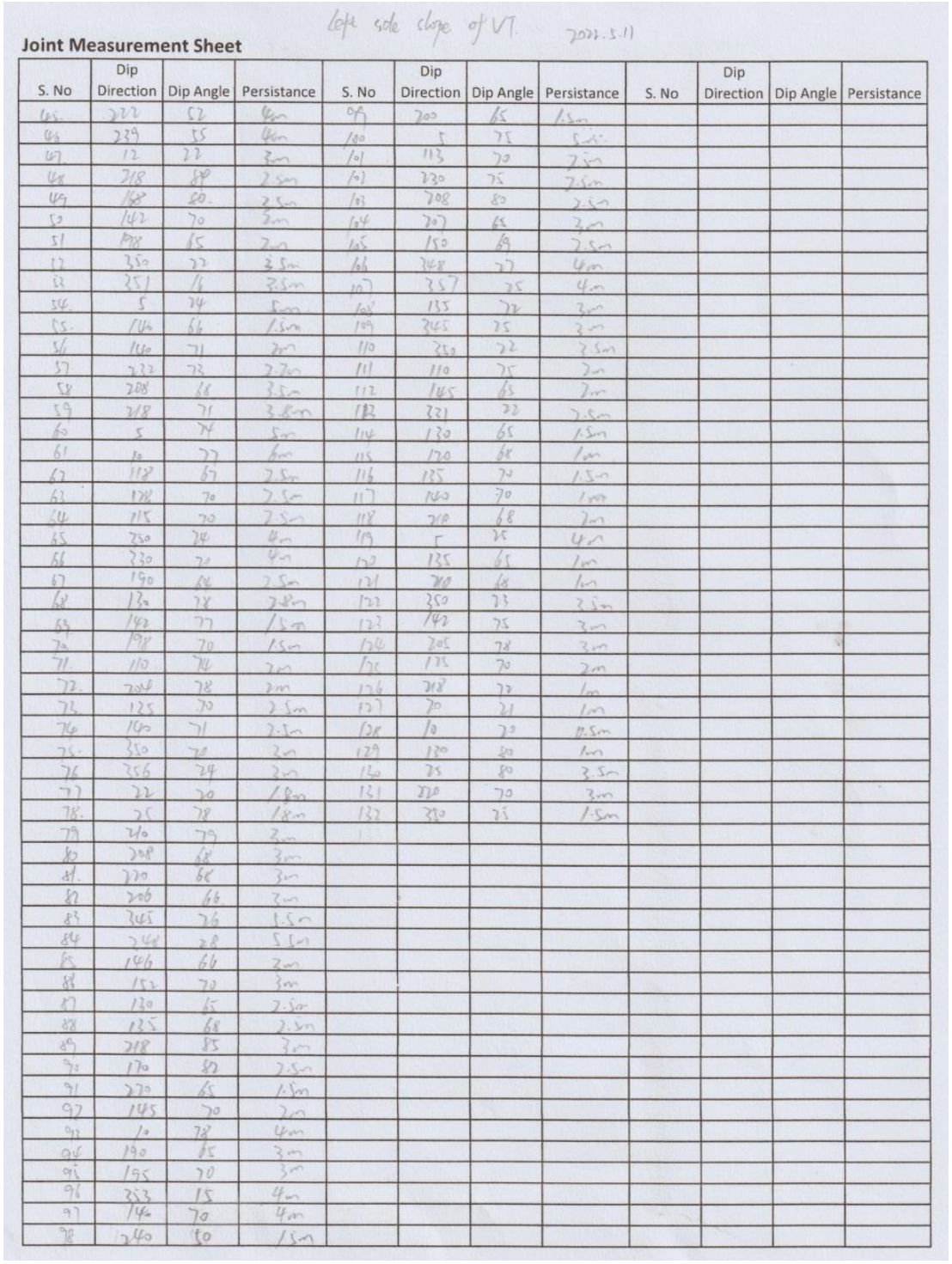
S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance
1	240°	50°	2m	23	190°	65°	2m				
2	220°	65°	2.5m	24	130°	80°	3.5m				
3	010°	20°	3.5m	25	142°	75°	4m				
4	218°	85°	2m	26	195°	70°	6m				
5	170°	82°	2m	27	110°	75°	5m				
6	140°	70°	1.5m	28	205°	78°	3m				
7	280°	65°	2.5m	29	135°	72°	6m				
8	350°	23°	3.5m	30	140°	70°	5m				
9	355°	15°	3m	31	350°	22°	3m				
10	005°	25°	2.5m	32	359°	25°	3.5m				
11	135°	65°	2m	31	020°	21°	2m				
12	145°	70°	3m	32	025°	80°	3.5m				
13	230°	75°	1.5	33	208	80	6m				
14	010°	68°	5m	34	210	69	6.5m				
15	218°	72°	3m	35	220°	70°	4m				
16	005	75°	1m	36	257°	65°	2m				
17	010°	78°	1m	37	345	25°	4m				
18	120°	68°	3m	38	348	27°	2.5m				
19	125°	70°	1.5m	39	145°	65°	2m				
20	113°	76°	2.5m	40	150°	69°	1.5m				
21	350°	25°	3m		130°	65°	3m				
22	331°	22°	3.5m		135°	70°	4.5m				
			MAT								
1	125°	55°	1.5m	21	090°	65°	4m				
2	145°	70°	1.5m	22	260°	70°	3.5m				
3	290°	65°	1m	23	355°	19°	2.5m				
4	340°	60°	2m	24	342°	22°	5m				
5	345°	20°	3m	25	210°	75°	4m				
6	355°	25°	3m	26	138°	65°	1.5m				
7	010°	19°	3.5m	27	1414	70°	1.5m				
8	110°	70°	2m	28	150°	72°	2m				
9	280°	85°	2.5m	29							
10	320°	20°	3m	30							
11	335°	28°	5m								
12	342°	26°	3m								
13	085°	76°	0.5m								
14	210°	80°	4m								
15	190°	82°	5m								
16	220°	65°	2.5m								
17	150°	60°	3m								
18	005°	20°	2m								
19	195°	75°	4m								
20	198°	70°	3m								

Statistics table 2

Joint Measurement Sheet Location: Right slope from VT 7077.5.9

S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance
1	205°	22°	4m	21	350°	85°	3m	41	349	25°	3m
2	010°	25°	4m	22	085	72°	1m	42	185	70°	3m
3	095°	85°	4m	23	352	28°	2m	43	095	70°	1.5m
4	110	80°	3.5m	24	090	75°	1.5m	44	200	75°	3m
5	135	48°	1m	25	085	70°	1.5m	45	210°	80°	4m
6	115	50°	0.5m	26	075	80°	1m				
7	350°	09°	3m	27	010°	29°	3m				
8	070°	87°	1.5m	28	356	25°	3m				
9	095°	85°	2m	29	052	72°	2m				
10	355	30°	3m	30	190	70°	4m				
11	146	75°	0.5	31	141	75°	2.5m				
12	090	60°	3m	32	140°	78°	1m				
13	240°	30°	5m	33	185	75°	3m				
14	356°	30°	2m	34	350	32°	5m				
15	353	28°	3m	35	354	25°	3m				
16	010°	25°	4m	36	141°	72°	4m				
17	020°	80°	3m	37	175	70°	2.5m				
18	315°	70°	2m	38	195	75°	3.5m				
19	000	75°	5m	39	190	80°	10m				
20	005°	22°	3m	40	115	70°	7m				
X			Ventilation		Tunnel						
1	340°	25°		X							
2	140°	65°	4m	21	135°	62°					
3	150°	60°	5m	22	130	65°					
4	130°	70°	4m	23	139	68°					
5	140°	65°	2m	24	125	65°					
6	130°	72°	5m	25	005	20°					
7	125°	69°	3m	26	110	75°					
8	130°	72°	2m	27	355	22°					
9	145°	70°	3m	28	135	62°					
10	352°	25°	4m	29	142	65°					
11	355°	23°	5m	30	138	70°					
12	005°	20°	4m	31	135	69°					
13	110°	70°	3m	32	330	22°					
14	120°	75°	2.5m	33	345	25°					
15	345°	25°	3m	34	120	70°					
16	350°	23°	3m	35	348	30°					
17	350°	27°	3m	36	134	72°					
18	127°	72°	3m	37							
19	130°	75°	4m	38							
20	155°	65°	2m								

Statistics table 3



left side slope of VT. 2022.5.11

Joint Measurement Sheet

S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance
46	222	52	4m	96	200	65	1.5m				
47	239	55	4m	100	5	75	5m				
48	12	22	3m	101	113	70	2m				
49	218	80	2.5m	102	230	75	2.5m				
50	182	80	2.5m	103	208	80	2.5m				
51	142	70	3m	104	207	65	3m				
52	198	65	2m	105	150	69	2.5m				
53	350	22	3.5m	106	348	27	4m				
54	251	14	3.5m	107	257	25	4m				
55	5	24	5m	108	135	22	3m				
56	146	66	1.5m	109	345	25	3m				
57	140	71	2m	110	250	22	2.5m				
58	222	72	2.7m	111	110	25	2m				
59	208	68	3.5m	112	145	65	2m				
60	218	71	3.8m	113	221	22	2.5m				
61	5	24	5m	114	130	65	1.5m				
62	10	22	6m	115	170	68	1m				
63	118	67	2.5m	116	185	24	1.5m				
64	178	70	2.5m	117	140	70	1m				
65	115	70	2.5m	118	210	68	2m				
66	250	28	4m	119	[illegible]	25	4m				
67	230	22	4m	120	135	65	1m				
68	190	64	2.5m	121	210	68	1m				
69	130	28	2.8m	122	350	23	2.5m				
70	142	77	1.5m	123	142	25	3m				
71	198	70	1.5m	124	205	28	3m				
72	110	24	2m	125	135	70	2m				
73	204	28	2m	126	248	22	1m				
74	125	70	2.5m	127	70	21	1m				
75	140	71	2.5m	128	10	20	1.5m				
76	350	20	2m	129	130	80	1m				
77	256	24	2m	130	25	80	3.5m				
78	22	20	1.8m	131	220	70	3m				
79	25	28	1.8m	132	230	25	1.5m				
80	210	29	2m								
81	208	68	3m								
82	220	68	3m								
83	206	66	2m								
84	245	26	1.5m								
85	246	28	5.5m								
86	146	66	2m								
87	152	70	3m								
88	130	65	2.5m								
89	125	68	2.5m								
90	218	85	3m								
91	170	82	2.5m								
92	270	65	1.5m								
93	145	70	2m								
94	10	28	4m								
95	190	85	3m								
96	195	70	3m								
97	353	15	4m								
98	140	70	4m								
99	240	50	1.5m								

Statistics table 4

Joint Measurement Sheet Right slope from VP. 2022.5.11.

S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance	S. No	Dip Direction	Dip Angle	Persistance
46	8	70	5m	100	95	85	1.5m				
47	8	75	6m	101	1	77	4m				
48	42	84	3m	102	135	88	2m				
49	100	79	4m	103	100	80	2m				
50	136	88	2m	104	1	77	1.5m				
51	140	50	2m	105	190	70	1.5m				
52	350	50	2.5m	106	10	25	2m				
53	70	85	3m	107	315	70	3m				
54	98	82	2.5m	108	175	70	1m				
55	354	78	5m	109	140	30	4m				
56	140	70	2.5m	110	195	70	2m				
57	222	58	1m	111	357	78	3m				
58	341	30	3m	112	355	30	2.5m				
59	269	30	3m	113	140	75	2m				
60	354	70	4m	114	350	75	4m				
61	10	74	2.5m	115	85	72	3m				
62	22	78	2.5m	116	145	75	4m				
63	214	71	1m	117	51	72	2.5m				
64	200	74	2m	118	349	75	1m				
65	6	70	5m	119	85	72	1.5m				
66	351	74	5m	120	115	70	2m				
67	81	73	3m	121	230	32	1.5m				
68	350	30	2m	122	356	76	3m				
69	95	76	2m	123	95	70	1.5m				
70	88	70	2m	124	185	70	2m				
71	74	79	2.5m	125	180	78	2m				
72	10	30	1m	126	240	80	2m				
73	355	76	4m	127	317	78	2.5m				
74	50	70	2m	128	90	75	2.5m				
75	188	68	2m	129	10	78	5m				
76	145	74	1.5m	130	356	25	4m				
77	138	78	2m	131	75	80	1m				
78	188	76	2m	132	180	75	2.5m				
79	350	30	4m	133	140	72	2.2m				
80	355	78	4m	134	200	75	2m				
81	142	72	2m	135	190	75	2.5m				
82	175	72	2m								
83	195	74	2m								
84	190	78	2.5m								
85	118	68	2m								
86	350	78	3m								
87	188	69	2m								
88	098	68	2m								
89	200	70	1.5m								
90	210	79	1.5m								
91	220	79	1m								
92	70	87	2m								
93	250	30	2m								
94	270	60	2.2m								
95	145	50	3m								
96	200	75	2m								
97	22	80	2m								
98	95	85	2m								
99	10	75	2m								

Statistics table 5

Ventilation Tunnel Joint Measurement Sheet								
S.No	Dip Direction	Dip Angle	S.No	Dip Direction	Dip Angle	S.No	Dip Direction	Dip Angle
1	205	40	41	110	50	81	355	27
2	353	18	42	200	51	82	3	29
3	20	20	43	200	79	83	5	23
4	340	20	44	357	28	84	6	26
5	160	85	45	101	63	85	5	27
6	175	85	46	150	60	86	3	29
7	160	85	47	140	68	87	2	22
8	160	85	48	112	75	88	1	20
9	175	85	49	105	71	89	357	24
10	175	85	50	125	58	90	355	29
11	40	75	51	150	50	91	1	22
12	310	85	52	108	70	92	200	38
13	150	55	53	29	66	93	358	20
14	175	85	54	29	69	94	18	20
15	95	85	55	25	67	95	350	20
16	175	85	56	23	70	96	158	84
17	180	80	57	30	71	97	170	80
18	180	80	58	142	69	98	165	80
19	40	70	59	23	70	99	162	80
20	160	85	60	14	69	100	170	78
21	40	70	61	17	72	101	170	79
22	40	70	62	120	65	102	38	75
23	160	85	63	155	58	103	312	85
24	160	70	64	140	71	104	150	56
25	40	70	65	343	49	105	175	82
26	89	67	66	330	68	106	96	82
27	295	70	67	140	71	107	176	83
28	95	60	68	130	70	108	182	82
29	5	45	69	340	68	109	181	78
30	5	45	70	155	70	110	40	68
31	160	70	71	15	69	111	155	82
32	160	70	72	17	70	112	38	68
33	160	70	73	335	60	113	40	68
34	250	71	74	125	76	114	158	82
35	200	79	75	355	21	115	158	68
36	160	75	76	358	24	116	39	67
37	200	79	77	5	30	117	88	66
38	356	24	78	6	22	118	292	68
39	1	30	79	7	26	119	94	60
40	40	70	80	358	25	120	8	44

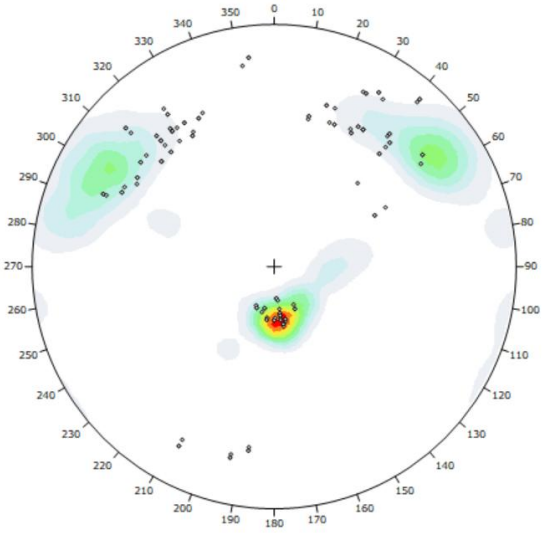
Statistics table 6

Ventilation Tunnel Joint Measurement Sheet								
S.No	Dip Direction	Dip Angle	S.No	Dip Direction	Dip Angle	S.No	Dip Direction	Dip Angle
121	6	42	161	154	69			
122	158	68	162	18	69			
123	159	68	163	18	65			
124	158	68	164	340	65			
125	252	70	165	128	75			
126	198	75	166	355	20			
127	158	74	167	356	25			
128	198	78	168	10	28			
129	352	25	169	8	25			
130	5	28	170	8	26			
131	35	67	171	355	25			
132	105	48	172	356	20			
133	197	48	173	10	20			
134	198	78	174	8	25			
135	355	30	175	10	24			
136	100	62	176	8	25			
137	148	58	177	10	28			
138	148	66	178	18	20			
139	110	74	179	2	20			
140	102	70	180	358	22			
141	122	57	181	358	24			
142	148	48	182	5	25			
143	107	68						
144	30	65						
145	30	67						
146	28	65						
147	25	70						
148	31	70						
149	143	68						
150	25	68						
151	18	72						
152	20	70						
153	122	68						
154	150	67						
155	138	70						
156	340	40						
157	332	65						
158	138	70						
159	135	68						
160	353	65						

Statistics table 7

Main Access Tunnel Joint Measurement Sheet								
S.No	Dip Direction	Dip Angle	S.No	Dip Direction	Dip Angle	S.No	Dip Direction	Dip Angle
1	5	20	41	260	75	81	140	58
2	285	75	42	19	14	82	141	70
3	170	78	43	140	69	83	143	66
4	160	80	44	85	60	84	241	45
5	160	80	45	359	25	85	188	70
6	160	80	46	3	20	86	163	63
7	255	54	47	10	23	87	142	54
8	247	67	48	8	26	88	313	65
9	195	69	49	5	24	89	18	15
10	210	71	50	10	20	90	255	70
11	160	80	51	284	74	91	20	15
12	350	10	52	168	75	92	138	66
13	205	68	53	165	78	93	84	58
14	200	66	54	164	75	94	357	23
15	130	63	55	167	77	95	5	22
16	20	63	56	254	50	96	15	25
17	22	67	57	244	65	97	10	24
18	22	65	58	198	64	98	6	22
19	296	55	59	208	68			
20	300	25	60	162	76			
21	7	28	61	352	15			
22	165	62	62	204	69			
23	210	75	63	206	65			
24	198	72	64	132	64			
25	17	68	65	22	20			
26	208	68	66	20	20			
27	242	70	67	20	64			
28	208	68	68	290	58			
29	14	15	69	298	64			
30	15	15	70	10	30			
31	16	70	71	160	64			
32	145	60	72	205	72			
33	142	71	73	199	70			
34	140	67	74	20	15			
35	245	47	75	205	67			
36	190	72	76	240	68			
37	165	65	77	205	70			
38	145	55	78	16	15			
39	145	69	79	20	15			
40	15	20	80	10	68			

Contour & pole plot、Rose diagram



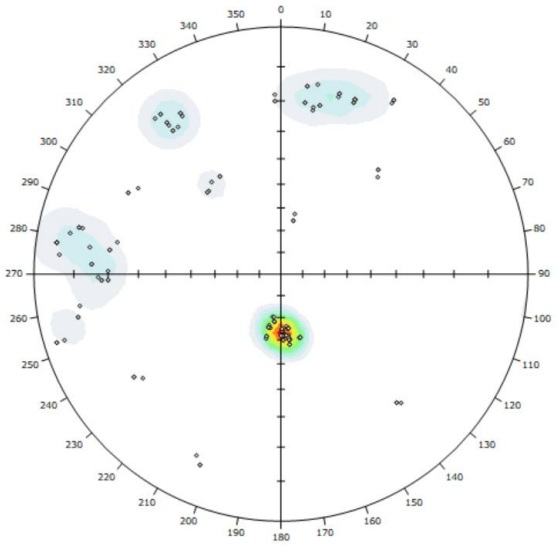
Symbol	Feature
◇	Pole Vectors

Color	Density Concentrations
	0.00 - 1.60
	1.60 - 3.20
	3.20 - 4.80
	4.80 - 6.40
	6.40 - 8.00
	8.00 - 9.60
	9.60 - 11.20
	11.20 - 12.80
	12.80 - 14.40
	14.40 - 16.00

Contour Data	Intersections
Maximum Density	15.15%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	132 (132 Entries)
Hemisphere	Lower
Projection	Equal Angle

Contour & pole plot (Left side slope of VT tunnel)



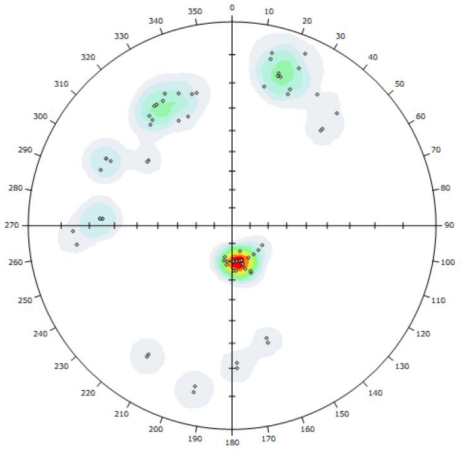
Symbol	Feature
◇	Pole Vectors

Color	Density Concentrations
	0.00 - 3.10
	3.10 - 6.20
	6.20 - 9.30
	9.30 - 12.40
	12.40 - 15.50
	15.50 - 18.60
	18.60 - 21.70
	21.70 - 24.80
	24.80 - 27.90
	27.90 - 31.00

Contour Data	Pole Vectors
Maximum Density	30.19%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	135 (135 Entries)
Hemisphere	Lower
Projection	Equal Angle

Contour & pole plot (Right side slope of VT)



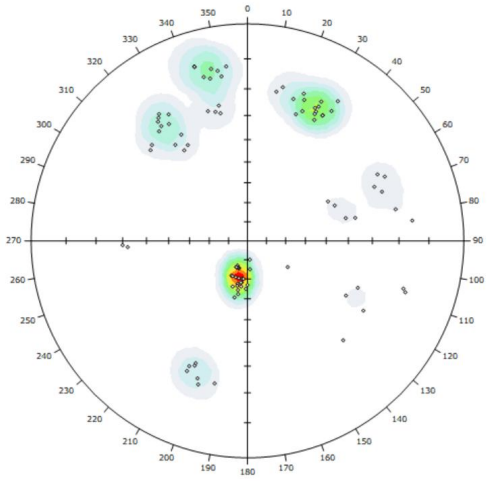
Symbol	Feature
◇	Pole Vectors

Color	Density Concentrations
	0.00 - 2.20
	2.20 - 4.40
	4.40 - 6.60
	6.60 - 8.80
	8.80 - 11.00
	11.00 - 13.20
	13.20 - 15.40
	15.40 - 17.60
	17.60 - 19.80
	19.80 - 22.00

Contour Data	Pole Vectors
Maximum Density	21.86%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	68 (68 Entries)
Hemisphere	Lower
Projection	Equal Angle

Contour & pole plot (slope of MAT)



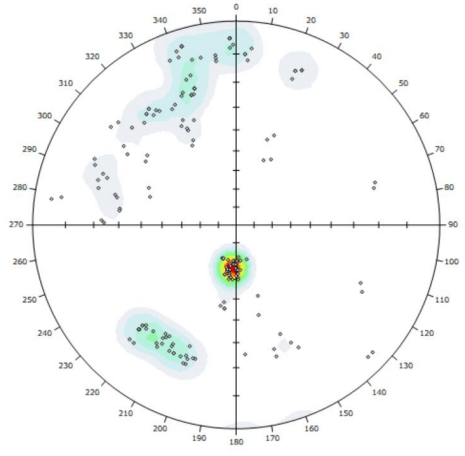
Symbol	Feature
◇	Pole Vectors

Color	Density Concentrations
	0.00 - 2.20
	2.20 - 4.40
	4.40 - 6.60
	6.60 - 8.80
	8.80 - 11.00
	11.00 - 13.20
	13.20 - 15.40
	15.40 - 17.60
	17.60 - 19.80
	19.80 - 22.00

Contour Data	Pole Vectors
Maximum Density	21.99%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	98 (98 Entries)
Hemisphere	Lower
Projection	Equal Angle

Contour & pole plot (MAT mapping)



Symbol	Feature
◇	Pole Vectors

Color	Density Concentrations
	0.00 - 2.20
	2.20 - 4.40
	4.40 - 6.60
	6.60 - 8.80
	8.80 - 11.00
	11.00 - 13.20
	13.20 - 15.40
	15.40 - 17.60
	17.60 - 19.80
	19.80 - 22.00

Contour Data	Pole Vectors
Maximum Density	21.25%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	182 (182 Entries)
Hemisphere	Lower
Projection	Equal Angle

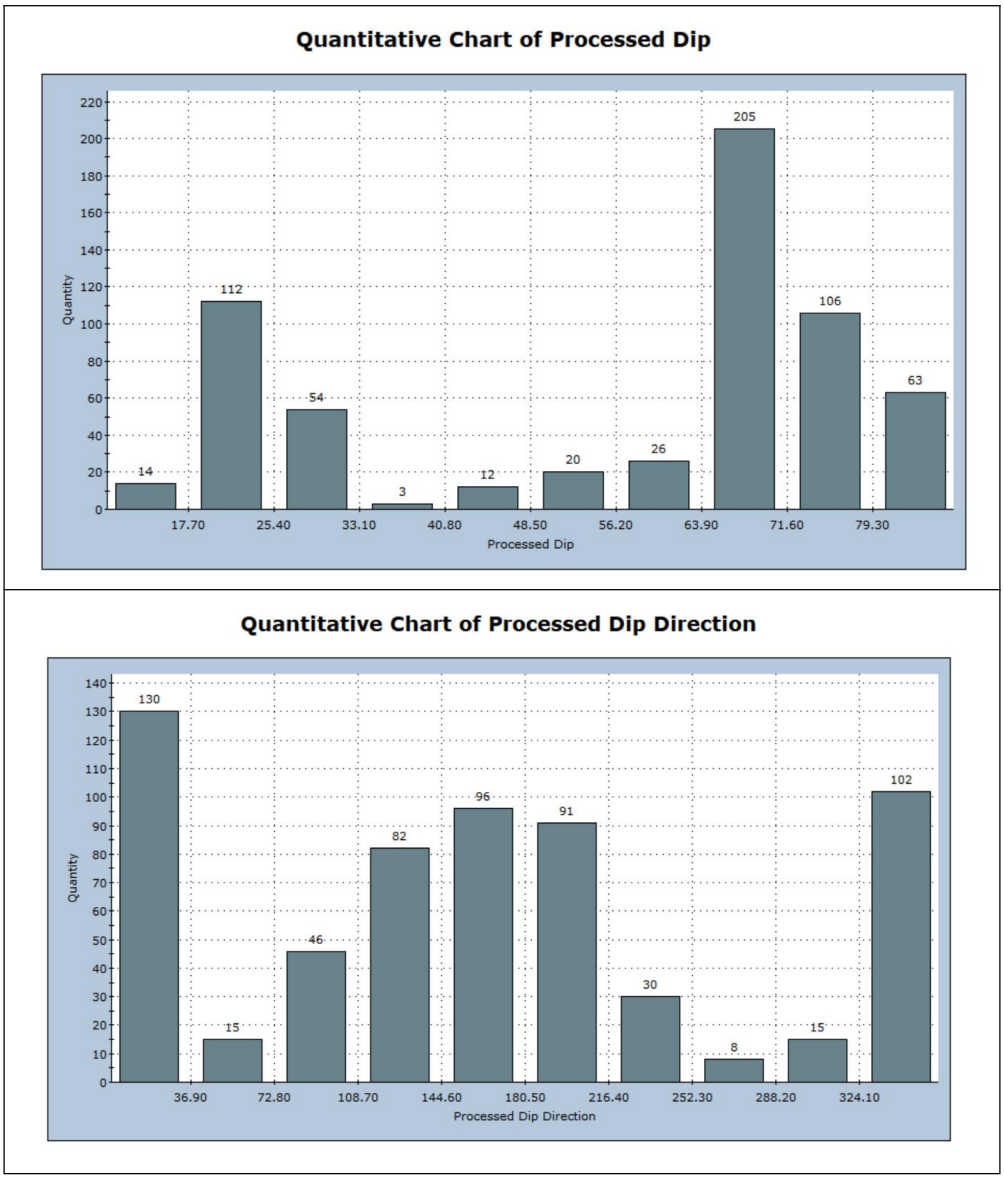
Contour & pole plot (VT mapping)

After all the joint statistics of several regions are collected,there are 615 joints,Through statistical analysis, there are 4 groups of joints with the most frequent distribution.

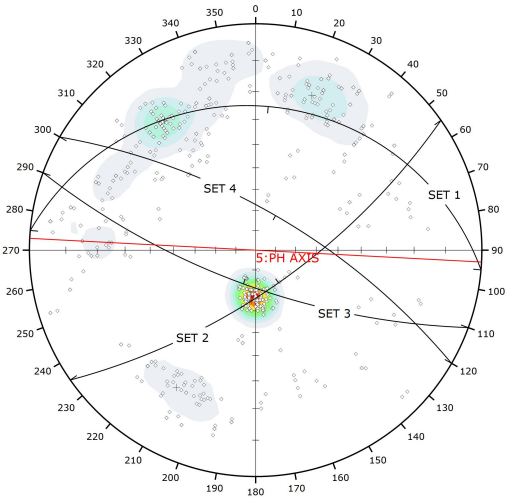
DIP/DIRECTION

SET 1: 15-30° /355-10° SET 2: 60-75° /135-150°

SET 3: 68-75° /198-208° SET 4: 65-72° /20-30°



Contour & pole plot

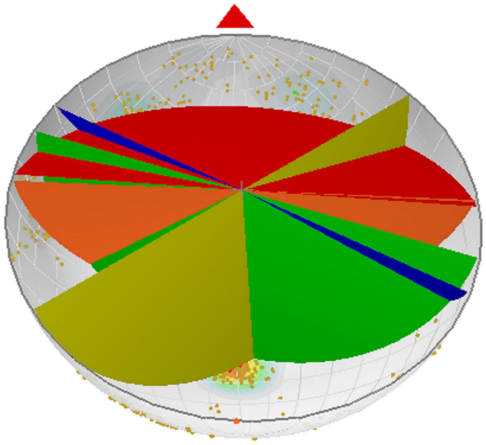


Symbol	ID			Quantity
◇	1.00	-	88.71	88
×	88.71	-	176.43	88
△	176.43	-	264.14	88
+	264.14	-	351.86	87
▽	351.86	-	439.57	88
□	439.57	-	527.29	88
◁	527.29	-	615.00	88

Color	Density Concentrations		
	0.00	-	2.10
	2.10	-	4.20
	4.20	-	6.30
	6.30	-	8.40
	8.40	-	10.50
	10.50	-	12.60
	12.60	-	14.70
	14.70	-	16.80
	16.80	-	18.90
	18.90	-	21.00

Contour Data	Pole Vectors
Maximum Density	20.49%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count (Weighted)	615 (615 Entries)
Terzaghi Weighting	Minimum Bias Angle 15
Hemisphere	Lower
Projection	Equal Angle

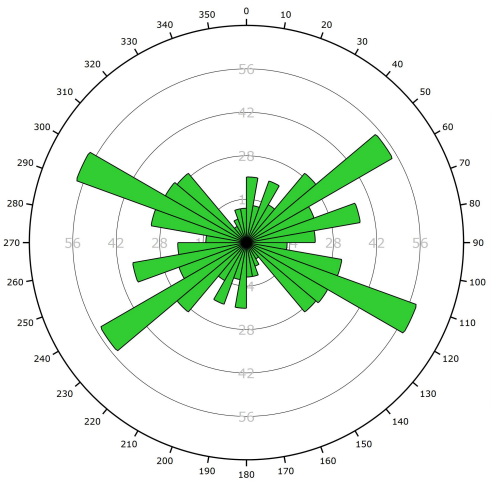


DIP/DIRECTION

SET 1: 15-30° /355-10° SET 2: 60-75° /135-150°

SET 3: 68-75° /198-208° SET 4: 65-72° /20-30°

Rose diagram



Plot Mode	Rosette
Plot Data	Apparent Strike
Face Normal Trend	0.0
Face Normal Plunge	90.0
Terzaghi Weighting	Minimum Bias Angle 15
Bin Size	10
Outer Circle	70 planes per arc
Planes Plotted	430
Minimum Angle To Plot	45.0
Maximum Angle To Plot	90.0